

STATE OF CALIFORNIA
EARL WARREN, Governor
DEPARTMENT OF NATURAL RESOURCES
WARREN T. HANNUM, Director

DIVISION OF MINES
FERRY BUILDING, SAN FRANCISCO 11
OLAF P. JENKINS, Chief

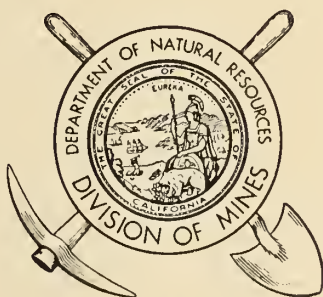
SAN FRANCISCO

SPECIAL REPORT 33

SEPTEMBER 1953

GEOLOGY OF THE
GRIFFITH PARK AREA
LOS ANGELES COUNTY, CALIFORNIA

By GEORGE J. NEUERBURG



Price 50¢



Digitized by the Internet Archive
in 2012 with funding from
University of California, Davis Libraries

<http://archive.org/details/geologyofgriffit33neue>

GEOLOGY OF THE GRIFFITH PARK AREA, LOS ANGELES COUNTY, CALIFORNIA

By GEORGE J. NEUERBURG *

OUTLINE OF REPORT

	Page
ABSTRACT	3
INTRODUCTION	4
IGNEOUS AND METAMORPHIC ROCKS	5
Metamorphic rocks	8
Petrogenesis	9
Plutonic igneous rocks	9
Vermont quartz diorite	10
Lar quartz diorite	11
Feliz granodiorite	12
Hypabyssal and extrusive igneous rocks	14
Geologic history	15
SEDIMENTARY ROCKS	16
Cretaceous (?) rocks	18
Griffith beds	18
Cahuenga beds	19
Tertiary rocks	20
Topanga formation	20
Hollycrest formation	23
Modelo formation	24
Quaternary alluvium	24
STRUCTURE	24
Faults	24
Folds	26
GEO MORPHOLOGY	27
GEOLOGIC HISTORY	27
ECONOMIC GEOLOGY	28
Quarries	28
Mines	28
Hollywood Lake	28
Engineering geology	28
REFERENCES	28

List of Illustrations

Plate 1. Geologic map and structure sections of the Santa Monica Mountains east of Cahuenga Pass and Dark Canyon	In pocket
Figure 1. Index map showing part of the Santa Monica Mountains	4
Figure 2. Major fault blocks of the Griffith Park area of the eastern Santa Monica Mountains	8
Figure 3. Sequence of crystallization in the consanguineous granitic rocks and in the associated dike rocks in the Griffith Park area	9
Figure 4. The nature of the contact zone of the Vermont pluton with the metamorphosed basic igneous rocks	10
Figure 5. Photo of discoidal biotite aggregates in the foliated part of the Lar pluton	12
Figure 6. The contact of the Feliz and Vermont plutons and associated metamorphosed basic igneous rocks	13
Figure 7. Schematic diagram of the 'web and inclusion' structure	13
Figure 8. Photo showing protomylonite structure along some of the faults in the Feliz pluton	13
Figure 9. Hypothetical structural relations of the two groups of basement rocks in the Santa Monica Mountains	16
Figure 10. Columnar sections of the fault blocks of the Griffith Park area	17
Figure 11. Generalized topography and geology of the Griffith Park area in middle Miocene	21
Figure 12. Photo of fragments of a shell limestone bed in intrusive basalt	21
Figure 13. Photo of basaltic graywacke of the middle member of the Topanga formation	22

Figure 14. Photo of a filled river channel in granodiorite	22
Figure 15. Photo of fault scarp and tunnel in fault gouge along the Tunnel fault	26

ABSTRACT

The area mapped in the Santa Monica Mountains is bounded on the south by Hollywood, on the north by the San Fernando Valley, on the west by Cahuenga Pass and Dark Canyon, and on the east by the Los Angeles River. Griffith Park is included within the eastern half of the area.

The principal topographic feature of the area is an east-west ridge. Cahuenga Peak (altitude 1821 feet) is near the western end of the ridge, and Mount Hollywood (altitude 1652 feet) is just south of the central part of the ridge. The ridge is in line with the crest of the Santa Monica Mountains, but they are separated by Cahuenga Pass, a low transverse saddle. The range is asymmetric, with the steeper slope on the north side.

The principal conclusion of this study is that the area east of Cahuenga Pass is a discordant structural and stratigraphic element in the Santa Monica Mountains. The basement rocks and the basement structure in Forest Lawn, east of the Los Angeles River, are like those in the Santa Monica Mountains west of Cahuenga Pass, but are displaced about 6 miles to the north. The Los Angeles River fault is hypothesized to explain these relations.

The basement rocks in Griffith Park are exposed in four areas, separated from one another by major faults. The age of the basement rocks is not known, but they are probably older than Upper Cretaceous. The stratigraphic position of these rocks relative to the basement rocks west of Cahuenga Pass and in Forest Lawn is not known. The largest area of crystalline rocks is in the southeast quarter of the area, where the oldest rocks are metamorphosed gabbro, diabase, and basalt. These rocks were intruded and metamorphosed by the Vermont quartz diorite; stopping was the probable mechanism of intrusion. A swarm of aplite dikes, related to the quartz diorite, is intrusive into the contact zone. The Vermont quartz diorite is intruded by the Feliz granodiorite, a massive igneous rock, which ranges in composition from quartz diorite to quartz monzonite. The irregular, granulated and slickensided contact with the Vermont quartz diorite plutonic body and with the metamorphic rock complex is interpreted as meaning intrusion by a nearly solid crystal-charged magma.

A fault block of foliated quartz diorite—Lar pluton—is exposed in the northeastern part of the area. The foliation, which is mainly due to aligned, disc-shaped aggregates of biotite, is probably a primary magmatic flow structure. Numerous irregular dikes of malchite and of basalt are intrusive into the Lar quartz diorite. There is a small fault block of granodiorite microbreccia near the western end of this exposure. A larger area of quartz diorite microbreccia is exposed in the central part of the area, and is intruded by an andesite porphyry dike. These plutonic rocks are questionably correlated with the Feliz granodiorite and Lar quartz diorite, respectively.

The sequence of crystallization, the simple mineralogy, the very slight deuteric alterations, the textural and compositional characters of the minerals, and the pleochroism and the odd habit of biotite crystals are the same in all of the plutonic igneous rocks. This observation is the basis for suggesting that these igneous rocks are consanguineous and derived from a common parent magma. The suggested sequence of intrusion is Vermont quartz diorite, Lar quartz diorite, and Feliz granodiorite.

The indurated sedimentary rocks are of Cretaceous (?) and of Miocene age; terrace deposits and alluvium are of Quaternary age. The major units are 1) the Griffith beds (Cretaceous ?); 2) the Cahuenga beds (Cretaceous ?); 3) the Topanga formation (middle Miocene); 4) the Hollycrest formation (middle Miocene); and 5) the Modelo formation (upper Miocene). The Griffith beds, the Cahuenga beds, and the Hollycrest formations are defined in this report.

An isolated fault block contains the Griffith beds—sandstone and fanglomerate—which may be the oldest sedimentary unit in

Department of Geology, University of California, Los Angeles. Condensation of a report submitted in partial fulfillment of the requirements for the degree Bachelor of Arts, including also later work. Manuscript submitted for publication June 1951.

the area. The Cahuenga beds are composed of reworked quartz diorite microbreccia, sandy boulder conglomerate with a thick lens of conglomeratic sandstone, and a well-bedded, coarse conglomeratic sandstone. The Cahuenga is separated from the overlying Topanga formation by a marked angular unconformity.

The Topanga formation consists of three members, separated by unconformities. The lowest member is interbedded arkose, acidic and basic tuffs, basalt agglomerate, basalt breccia, basalt flows, and many irregular intrusions of basalt. It is unconformably overlain by the middle member of interbedded pebble conglomerate, sandstone, and shale, all composed mainly of basaltic detritus. In view of the unusual composition and the typical graywacke texture, these rocks are called basaltic graywacke. The middle member is missing west of the Brush Canyon fault. The upper member of the Topanga formation is arkose and conglomeratic arkose, with a few thin beds of acidic tuff and thin-bedded siltstone. A single massive basalt sill is present in one place along the base of this member.

The Hollycrest formation consists of thin-bedded silty clay shales interbedded with medium-grained arkose. On the north side of Griffith Park, this formation has a thick basal member of sandy boulder conglomerate. In Cahuenga Pass the shale and sandstone unconformably overlie the upper member of the Topanga formation. East of the Cahuenga fault the Hollycrest rests unconformably on the conglomerate of the Cahuenga beds and on the lower member of the Topanga formation.

The Modelo formation is found only in the eastern part of the area where it lies unconformably on the Feliz granodiorite and on the conglomerate of the Hollycrest formation. The rocks are tan to brown organic clay shale and arkose, with thin limestone beds. They contain abundant fragments of wood.

Terrace deposits are on the southern and eastern flanks of the mountains and along the sides of canyons. They consist of the rock types which crop out in the vicinity, and are poorly indurated.

Faults are the major structural feature of this area; five major faults separate the area into six fault blocks. The fault block pattern has exerted a major influence on the stratigraphic evolution of the area. The north-trending Cahuenga block on the west side of the area is defined by the Cahuenga and Brush Canyon faults. Vertical movement along these faults is probably greater than 7,000 feet. The Griffith block bounds the north side of the Cahuenga block. The minimum vertical throw on the boundary faults of the Griffith block is probably about 5,000 feet. The microbreccias and the greatest thicknesses of sediments are exposed in these two blocks.

The Ferndell block, on the southeast corner of the Cahuenga block, is bounded by the Brush Canyon and Ferndell faults; it contains most of the intrusive basalt in the area, and probably was one of the major volcanic centers in the Santa Monica Mountains. The Riverside block, the northernmost in the area, and the Mount Hollywood block, in the southeast quarter of the area, contain most of the plutonic rocks.

Three groups of fold axes are present in the area. The oldest—in the Griffith formation—is unrelated to the fault block structure, whereas the others clearly reflect the pattern of fault blocks.

Quarries for road metal and concrete aggregate were the only successful mining activity in this area; they are now abandoned.

INTRODUCTION

Location. The eastern end of the Santa Monica Mountains is a discordant topographic and geologic block that is separated from the rest of the Santa Monica Mountains by Cahuenga Pass and the Cahuenga fault. The stratigraphy, structure, and geologic history of the rocks that are older than upper Miocene are different from the stratigraphy, structure, and geologic history of the rocks in the rest of the Santa Monica Mountains.

The area that is described in this report is shown on the index map. It is in the parts of the Burbank and the Glendale quadrangles that are bounded approximately by longitudes $118^{\circ}16'$ and $118^{\circ}20'$ west, and by latitudes $34^{\circ}06'$ and $34^{\circ}10'$ north. About 15 square miles are mapped. The area is bounded on the west, from south to north, by Highland Ave., by Cahuenga Pass, and by Dark Canyon (Barham Blvd.); on the north and east,

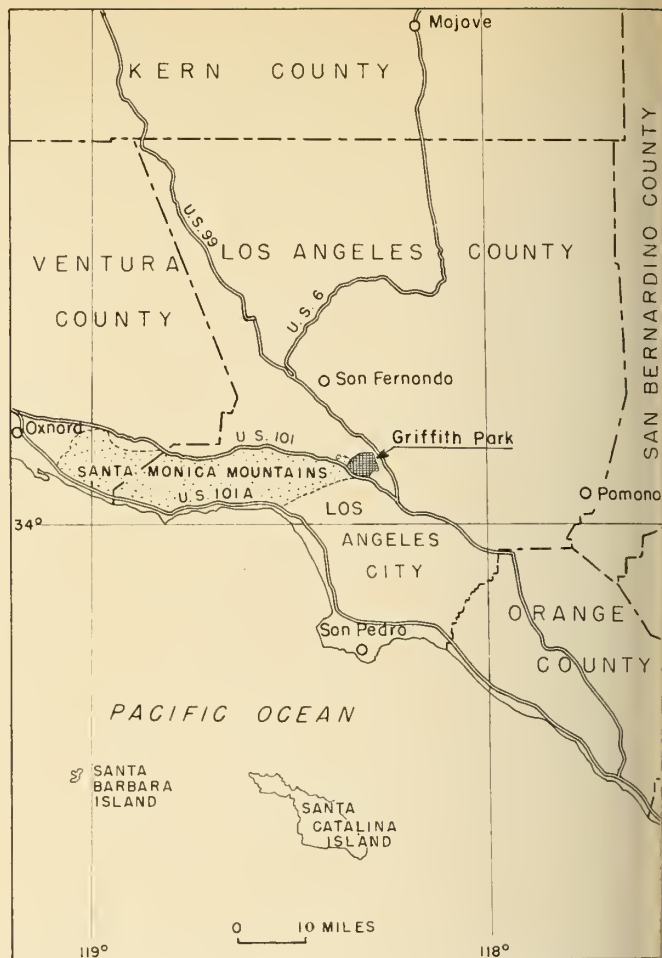


Figure 1. Index map showing the part of the Santa Monica Mountains described in this report.

by the Los Angeles River; and on the south, from west to east, by Hollywood Blvd., by Western Ave., and by Los Feliz Blvd. The area is within the Los Angeles City limits. Hollywood is on the south side, Glendale on the east side, and Burbank and Universal City on the north side of the area.

Geography. An east-west ridge, in line with the main crest of the Santa Monica Mountains, is the principal topographic feature of the area. Cahuenga Pass, a local gap, separates this ridge from the main crest of the Santa Monica Mountains. The highest point on the ridge is Cahuenga Peak (altitude 1821 ft.); the highest point in Cahuenga Pass is 714 feet. Mount Hollywood (altitude 1652 ft.) is on a ridge extending south from the main ridge, about a third of the distance from the Los Angeles River to Cahuenga Pass. The range is asymmetric, being steeper on the north. The Santa Monica Mountains terminate abruptly on the east against the Los Angeles River which has a nearly north-south course along this end of the mountain range. Altitudes range from 375 feet at Highland Ave. and Hollywood Blvd. to 1821 feet at Cahuenga Peak.

Canyons on the south flank trend from north to south. On the north flank, the largest canyons trend east-west.

and the smaller canyons trend north-south. Canyons are deeper and narrower on the south flank of the ridge than on the north. An alluvial fan flanks the southern edge of the area; in some places, the upper part of this fan is eroded. The Los Angeles River is pushed against the Santa Monica Mountains on the north side and on the east end by the large alluvial fan of the Verdugo Hills. A narrow alluvial fan, derived from the Santa Monica Mountains, lies between the Los Angeles River and the Santa Monica Mountains.

The climate is Mediterranean. Rainfall is concentrated in the winter months. The south flank of the ridge faces seaward, and most of the rain falls on the seaward slope. The streams are intermittent, and they are dry in early summer, depending on the total amount of rainfall. The soils are generally thin, but they are fertile in most places and they support a thick growth of chaparral.

Use. Griffith Park, the largest municipal park in the world, occupies the eastern half of the area. Col. G. J. Griffith gave the park to Los Angeles City in 1898. Part of Brush Canyon, on the west side of the park, was added to the park after World War II. Numerous picnic sites, trails, and roads were built in Griffith Park by the U. S. P. A. in the 1930's. Griffith Observatory was built in 1913 and 1933. The park contains a municipal golf course, a zoo, and a Greek theatre.

Hollywood Lake is a reservoir that belongs to the Los Angeles Department of Water and Power. The reservoir is part of the Owens River water system of Los Angeles County.

Concrete aggregate and road metal were quarried in several places in Brush Canyon between 1913 and 1929. The Mexicans are rumored to have had a gold mine in this area; they did mine and calcine a small amount of calcite. An abandoned copper prospect is present in Brush Canyon.

The Don Lee Broadcasting system has a television station on the next peak east from Cahuenga Peak; this peak is called "Mt. Lee" (alt. ca. 1700 ft.). The quarry on the east side of Brush Canyon is used for stock scenery by Westerns by moving picture companies. Forest Lawn Cemetery recently acquired part of Rancho Providencia—part that includes the large valley on the north side of this area. The southern foothills are a heavily settled suburb of Hollywood.

Accessibility. The area is easily accessible, as numerous trails and roads traverse much of it. An excellent network of roads surrounds the area. The Observatory, the Greek theatre, and the zoo are served by public transportation.

Except for the settled parts of the area, exposures are numerous and the rocks are fresher in this area than they are in any other part of the eastern Santa Monica Mountains. Areas of basalt, sandstone, and shale support a thick cover of brush. Most of these rocks are the parts of the area having the greatest number of trails and roads. Conglomerate and granitic rocks have little soil cover, which supports a thin, stunted growth of chaparral.

Field Work and Acknowledgments. Most of the mapping was done during the spring and summer of 1945,

but the basement rocks were mapped during the summer of 1949. Approximately 70 days were spent in the field. The map was drawn on U. S. G. S. quadrangle maps that were photographically enlarged from a 1:24,000 to a 1:12,000 scale. The work done in 1945 was used for a senior problem in geology at the University of California, Los Angeles.

Acknowledgment is made to the following people for their help: James Gilluly, Cordell Durrell, Joseph Murdoch, W. P. Popenoe, W. P. Woodring, W. T. Rothwell, Jr., Thane McCulloh, and John DeGrosse.

Permission to enter the property of the Don Lee Broadcasting System and of Hollywood Lake was freely given by the owners.

Previous Work. The geology of the Santa Monica Mountains has not been investigated in great detail. The most complete earlier work is that of Hoots (1931) on the Santa Monica Mountains east of Topanga Canyon. Later, in 1932 he published a brief résumé of his earlier work in the 15th guidebook of the 16th International Geological Congress. Hoots (1931) gives an excellent résumé of the geologic work in the Santa Monica Mountains before 1931. Except for a short note on the mineral occurrences of the eastern Santa Monica Mountains (Neuerburg, 1951a, p. 156), later publications do not refer to the Griffith Park area.

Students at the University of California have mapped much of the eastern Santa Monica Mountains. J. B. Klecker (ca. 1935) mapped Griffith Park for a senior problem at the University of California, Los Angeles. C. M. Anheier, Rodger Hayward, and L. Grumbine (1935) made a model from Klecker's map. This model is displayed in the Griffith Observatory.

Information on the detailed geology of the Santa Monica Mountains west of Cahuenga Pass was obtained from Hoots (1931), the M. A. theses of Jack G. Elam (1948), John T. McGill (1948), John N. Truex (1950), John N. Terpening (1951), and George C. Hazenbush (1950), and from the author's Ph. D. thesis on the basement rocks west of Cahuenga Pass (1951); the information on Forest Lawn is taken from A. W. Stepper's report (1951) and from the author's observations.

IGNEOUS AND METAMORPHIC ROCKS

Basement rocks are present in five of the fault blocks of the Griffith Park area (pl. 1). They are unconformably overlain by sediments of Cretaceous (?), middle and upper Miocene, and Quaternary ages. Two exposures of basement rocks are in fault contact with the sediments and are not overlain by sediments. A very small part of the detritus in the sedimentary rocks is derived from these basement rocks.

The basement rocks are metamorphosed basic igneous rocks, biotite quartz diorites, and biotite granodiorite. For convenience, each of the granitic rocks is named. The granitic rocks are consanguineous, and are dissimilar to the biotite-hornblende quartz diorites of the Nichols pluton (Neuerburg 1951c) west of Cahuenga Pass and in Forest Lawn. At least four periods of plutonic intrusion are represented.

A roof pendant of metamorphosed gabbro, diabase, and basalt is intruded in the Mount Hollywood block, by the

Table 1. *Sequence and character of the rocks in Griffith Park.*

Formation	Map symbol	Thickness (feet)	Lithology and remarks	Age
YOUNGER ALLUVIUM	Qya	30+	Unconsolidated stream gravels and fanglomerate; illsorted.	Quaternary: Recent
--- UNCONFORMITY ---				
OLDER ALLUVIUM	Qoa	100+	Poorly consolidated stream gravels and fanglomerate; poorly sorted.	Quaternary: Pleistocene?
--- UNCONFORMITY ---				
MODELO FORMATION	Tm	1,000+	Dark gray organic and calcareous siltstone and shale, with lenses and thin beds of fine-grained argillaceous limestone. Abundant wood fragments and fish scales. Small basalt sill.	Tertiary: Upper Miocene
--- CONTACT NOT EXPOSED ---				
HOLLYCREST FORMATION Upper member	Thsh	1,000+	Medium to fine-grained, thin-bedded arkose and light-colored silty clay shale, in ratio of about 5:1. A few thin beds of granitic cobble conglomerate in the lower part. A few fish scales. Small basalt sills.	Tertiary: Middle Miocene
Lower member	Theg	700+	Coarse sandy granitic pebble-boulder conglomerate, containing scattered, thin lenses of thin-bedded shale and arkose. Fragments are predominantly granitic. Localized occurrence in the Griffith block.	
--- UNCONFORMITY ---				
TOFANGA FORMATION Upper member	Ttpu	1,000+	Coarse and medium-grained conglomeratic arkose, poorly bedded to massive. Local thin beds of silty clay shale, alkali trachyte tuff, and impure tuff. Few, poorly preserved fossil shells. Basalt sill along the basal unconformity in one place.	Tertiary: Middle Miocene
--- UNCONFORMITY ---				
Middle member	Ttpm	1,400	Basaltic graywacke; illsorted conglomerate, sandstone and shale, composed essentially of basaltic detritus. Nonbasaltic detritus less than 5 percent. One thin flow with pillow structure. Dark chocolate brown rocks. Unfossiliferous.	
--- UNCONFORMITY ---				
Lower member	Ttpl	2,500 ±	About 800 feet of brown medium to coarse-grained arkose, talus breccia, white arkose, alkali trachyte tuff, and shell limestone; interbedded with basalt flows, flow breccias, tuff, agglomerate, and water-laid agglomerate. Intruded by numerous sills, dikes, and irregular bodies of basalt. Forms a complex and chaotic inclusion structure in areas of much basalt. The basalt is characterized by a high soda content, expressed by much analcite. Locally, poorly preserved fossil shells.	
--- (BASALT) ---	b			
--- UNCONFORMITY ---				
CAHUENGA BEDS Conglomeratic sandstone member	Kcs	1,000+	Coarse-grained, thin-bedded conglomeratic feldspathic sandstone, with discontinuous shale partings. Boulders of pink granite evenly distributed throughout the entire unit. Graded bedding in sandstone beds. Fish scales common in shale partings.	Cretaceous (?)
Sandy conglomerate member	Kcsg	300 ±	Sandy granitic cobble conglomerate, containing abundant cobbles of diabase and pebbles of quartzite. Scattered boulders. Resistant to erosion.	
Conglomerate member & Sandstone lens member	Kceg Kcsl	2,600 ± 700+	Massive, coarse, illsorted boulder conglomerate containing abundant pebbles of acidic porphyries and quartzite. A large lens of coarse-grained conglomeratic sandstone near the base of the conglomerate. Basalt intrusions.	
Breccia member	Kcb	700+	Light gray angular to subangular breccia, composed of fragments of the underlying quartz diorite microbreccia and of the associated andesite dikes. Basalt dike.	
--- CONTACT NOT EXPOSED ---				

Cretaceous (?)

grained arkose with beds of white clay shale, siltstone, and pebble conglomerate; uncommon fish scales; 2) 150 feet of thick-bedded, massive cobble conglomerate and coarse-grained arkose with uncommon silty clay shale partings; 3) 350 feet of massive, even-textured boulder conglomerate; and 4) 1500 feet of massive ill-sorted sandy boulder fanglomerate. Boulders are largely composed of rock types typical of and exposed in the Verdugo Hills and in the San Gabriel Mountains.

Pre-Cretaceous (?)
(lower age limit unknown)

Small irregular dike of blue andesite porphyry intrusive into the quartz diorite microbreccia in the Cahuenga Peak block.

Aphanitic to porphyritic, medium-grained panautomorphic rocks, containing altered andesine, clinzoisite, chlorite, and montmorillonite-nonttronite. Intrusive into the Lar pluton, in the Riverside block only.

Hypautomorphic, fine to medium-grained. Ranges in composition from quartz diorite to quartz monzonite. Biotite, oligoclase, quartz, and microcline are the principal minerals. Forms a microbreccia (Fgb) at the western end of the Riverside block. Except for the microbreccia, this rock is confined to the Mount Hollywood block, where it is in intrusive-fault contact with older quartz diorite and with metamorphosed basic igneous rocks.

Xenomorphous-hypautomorphic, fine to medium-grained. Separated into three parts: 1) foliated biotite quartz diorite (Lqp); 2) massive biotite quartz diorite (Lqe); and 3) sheared biotite quartz diorite. (Lqs). Calcic oligoclase, quartz, and biotite are the essential minerals, with small amounts of hornblende and microcline in a few places. Present as large blocky inclusions (Lqm) in the Feliz pluton, and as a microbreccia (Lqb) in the Cahuenga Peak block. Makes up the entire exposure in the Riverside block. Correlations with the inclusions and with the microbreccia and the relative age of this pluton are based on petrographic comparisons with the Feliz and Vermont plutons, with which the Lar pluton forms a consanguineous group.

Hypautomorphic, medium-grained. Andesine, biotite, and small amounts of quartz and hornblende. Accompanied by numerous dikes of quartz monzonite aplite. Contains a thick border of fine-grained quartz diorite (Vqe) where in contact with older rocks. Contains numerous inclusions of the border rock and of the metamorphic basic rocks that it intruded. Present only in the northern half of the Mount Hollywood block, where it intruded and metamorphosed a complex of basalt, diabase, and gabbro.

Metabasalt: fine-grained, relic intergranular texture. Labradorite-andesine, hornblende, biotite, and a small amount of quartz.

Metadiabase: fine-grained blastodiabasic. Labradorite-andesine, hornblende, tremolite, biotite, epidote, and chlorite, with a small amount of quartz.

Metagabbro: coarse-grained, blastoxenomorphous. Bytownite-labradorite, hornblendes, anthophyllite, tremolite, actinolite, biotite, and chlorite. Relics of hypersthene and of olivine are present in places.

A complex mosaic, much faulted, forming one or two roof pendants on the Vermont pluton in the Mount Hollywood block.

--- UNCONFORMITY

ANDESITE PORPHYRY

MALCHITE

FELIZ GRANODIORITE

LAR QUARTZ DIORITE

VERMONT QUARTZ DIORITE

METAMORPHOSED DIABASE, BASALT, AND GABBRO

ap

m

Fg

Fgb

Lqp

Lqe

Lqs

Lqm

Lqb

Vq

Vqc

mg

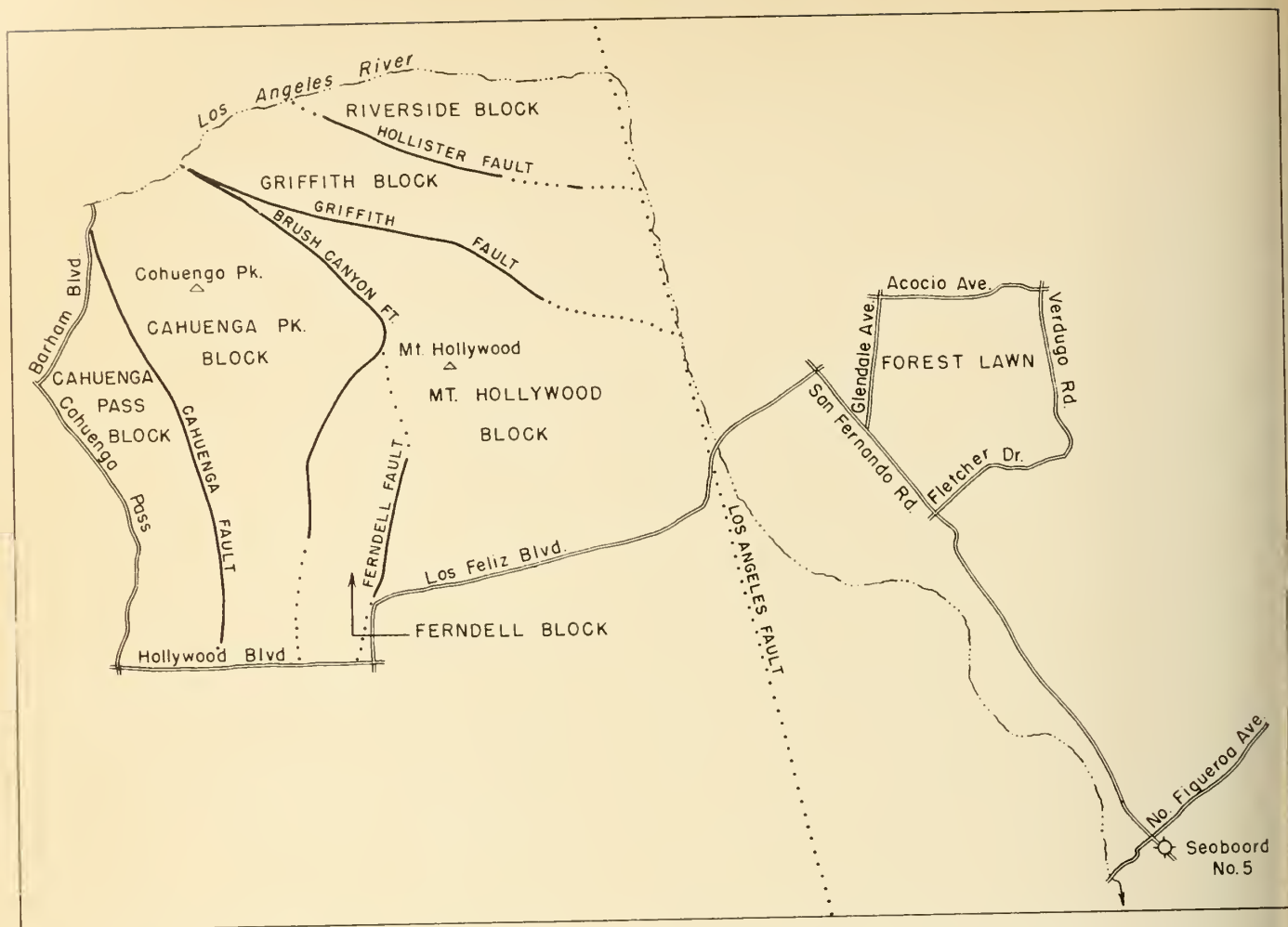


Figure 2. Major fault blocks of the Griffith Park area of the eastern Santa Monica Mountains, showing the position of Forest Lawn and the position of the Seaboard exploratory well that penetrated rocks of the Santa Monica formation, exposed west of Cahuenga Pass.

Vermont quartz diorite. The Vermont quartz diorite is intruded by the Feliz granodiorite, which contains inclusions of an older quartz diorite that is different from the Vermont quartz diorite and is possibly part of the Lar quartz diorite. The Topanga formation overlies these rocks on the western side. The Hollycrest and Modelo formations overlie the igneous rocks on the eastern side. Basalt dikes in the igneous rocks are abundant in a few places.

The Lar quartz diorite is the only rock unit in the Riverside block (pl. 1); it consists of interdigitating sheets of foliated biotite quartz diorite, massive biotite quartz diorite, and sheared quartz diorite. This quartz diorite is intruded by thin dikes of basalt and by numerous dikes of malchite. The Riverside block contains no pre-Quaternary sedimentary rocks.

A small fault block of Feliz (?) biotite granodiorite microbreccia is present in the Griffith block, near its western end. Lar (?) biotite quartz diorite microbreccia is exposed in the Cahuenga Peak block, and is intruded and metamorphosed by a few dikelets of quartz diorite aplite. A dike of pre-Cretaceous andesite porphyry and dikes of Miocene basalt are intrusive into the Lar (?) breccia. Cretaceous (?) breccia of the Cahuenga beds unconformably overlies and is derived from the Lar (?) breccia.

Metamorphic Rocks

The oldest rocks in this area are metamorphosed gabbro and olivine gabbro. The metagabbro contains dikes of metadiabase and of metabasalt. These rocks are present as one or two roof pendants and as inclusions in the Vermont quartz diorite.

Metagabbro. Outcrops of metagabbro are deep weathered, dark bluish gray to black, much fractured, and veined by carbonate. Dark greenish black, fresh nodules occur in the weathered rock. The texture of the metagabbro is blastoxenomorphic, coarse-grained, and inequigranular. All exposures of the rock are massive.

The composition of the metagabbro is not uniform; the unmetamorphosed rocks probably ranged from clinopyroxene gabbro to clinopyroxene-hypersthene-olivine gabbro. Thick tabular, euhedral to subhedral crystals of plagioclase range in composition from labradorite to bytownite. Slight albitization of the cores of some crystals and replacement by amphiboles in some specimens are the only alterations of plagioclase.

Amphiboles are the principal mafic constituents of the metagabbro. The amphiboles are secondary and represent the principal metamorphic change in the metagabbro. They consist of common green hornblende, brown horn-

lende, blue-green hornblende, anthophyllite, tremolite, and actinolite. Zonal relations are common. The amphiboles are replaced by a small amount of clinocllore and epidote. Relics of hypersthene and of olivine in these amphiboles have been partly or completely replaced by arbonate, by chalcedony, and by veinlets of bowlingite.

Metadiabase. Metadiabase occurs as irregular masses in fault contact with all other rocks, as inclusions in the Vermont quartz diorite, and as dikes in the metagabbro. Most outcrops are weathered; both fresh and weathered specimens are dark gray to black.

The texture is blastodiabasic, fine to medium-grained; the finer grained varieties are blastoporphyrific. The only textural changes are those resulting from the recrystallization of the ferromagnesian minerals to amphibole, hornblende, biotite, and epidote.

The composition is 50-55 percent plagioclase, 30-40 percent hornblende, 1-5 percent biotite, 10 percent chlorite, 5 percent quartz, and 0-2 percent epidote. Plagioclase ranges in composition from labradorite to bytownite; alterations are slight and consist of replacement by albite, sericite, and a fibrous zeolite along cleavage cracks. In some specimens, hornblende is partly replaced by tremolite. Epidote and biotite replaced amphiboles and they are replaced by penninite. Apatite is the only accessory mineral.

Metabasalt. Irregular dikes of metabasalt are common in metadiabase and in metagabbro. The Vermont quartz diorite contains many fragments of metabasalt. The weathered and the fresh rock are almost black; most exposures are fresh. Weathered specimens are friable and contain numerous carbonate veinlets.

The former igneous texture is well preserved; it was porphyritic to seriate with an intergranular groundmass. The structure in the groundmass is shown by the crude parallelism of tabular plagioclase crystals and by the zoning of the fabric around phenocrysts. In outcrop, the texture appears to be massive.

The composition is 55-60 percent andesine-labradorite, 10 percent hornblende, 15 percent biotite, and 0-5 percent quartz. Granules of opaque iron minerals and euhedral crystals of apatite and zircon are present in small amounts. Phenocrysts of plagioclase comprise 5 percent of rock.

The principal metamorphic changes were recrystallization of ferromagnesian minerals to small granules and to prisms of common green hornblende, and to poikiloblastic biotite crystals; the plagioclase crystals are unaltered. The optical properties of biotite crystals are exactly like those of the biotite crystals in the Vermont quartz diorite; the biotite may have been introduced from the Vermont magma during metamorphism.

Diagenesis

Metamorphism of the basic rocks in this area is confined to hydrothermal alteration of mafic minerals, in the complete absence of shearing stress. Addition of volatile substances, principally water, is postulated to explain the recrystallization of low grade amphiboles from former hornblende and olivine. The specimens of metabasalt that are included in the Vermont quartz diorite differ from other specimens of metabasalt only by having larger amounts of biotite and hornblende. This seems most rea-

Table 2. Mineralogic compositions of the plutonic igneous rocks in Griffith Park. The insignificant amounts of minor accessory minerals and of alteration products are not included.

	Estimated percentage of mineral constituents				
	Plagioclase	Microcline	Quartz	Biotite	Hornblende
<i>Rocks of the Vermont pluton</i>					
Chilled border part.....	60-75	-----	10-20	5	0-2
Main part.....	55-80	0-1	5-30	5-15	tr-5
Aplite & pegmatite.....	5-35	35-60	30	5	-----
<i>Rocks of the Lar pluton</i>					
Massive part.....	50	10	30	9	1
Foliated part.....	50	-----	40	10	-----
Sheared part.....	55	-----	40	5	-----
Alaskite.....	20	40	35	1	4
Inclusions in Feliz pluton.....	65	tr	20	15	-----
Microbreccia.....	50	0-2	35	10-15	-----
<i>Rocks of the Feliz pluton</i>					
All parts.....	30-60	10-25	25-40	5-10	-----
Aplite.....	25	35	39	1	-----
Microbreccia.....	45	25	25	5	-----

sonably explained by the assumption that a small amount of water, iron, and potash have been introduced from the Vermont magma.

Plutonic Igneous Rocks

The Vermont and Lar quartz diorites and the Feliz granodiorite are three separate intrusions, which with their associated dikes, two areas of microbreccia, and the inclusions of quartz diorite in the Feliz granodiorite form a closely related group. Except for small variations in the actual amounts of the minerals, all the igneous rocks have these same characteristics: 1) all of the minerals have the same minor, non-specific properties; 2) an unusual sequence of crystallization—especially the

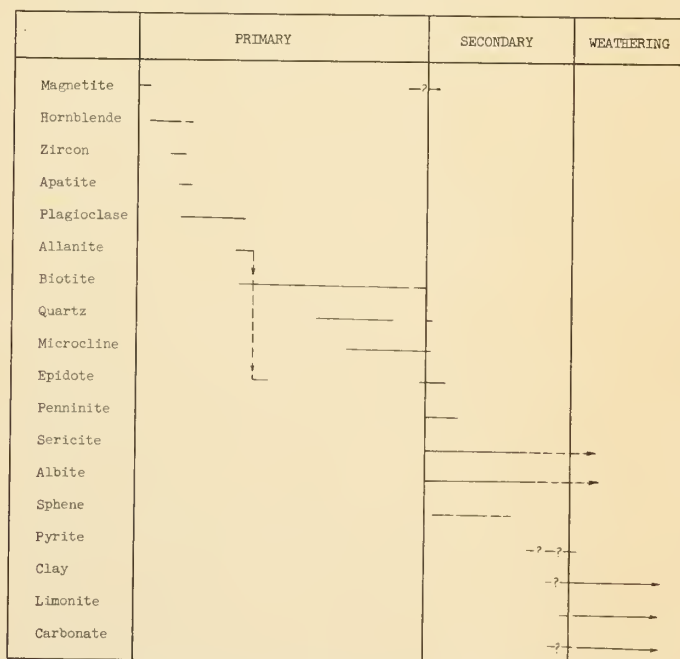


Figure 3. Sequence of crystallization in the consanguineous granitic rocks and in the associated dike rocks in the Griffith Park area.

late position of biotite; 3) biotite has a space-filling habit; and 4) very slight deuterie alteration. The rocks of the Lar and Feliz intrusions contain high percentages of quartz that correspond to silica percentages that are equal to or greater than those in most granites (Daly, 1933, table 1); no evidence whatsoever suggests a replacement—or introduced—origin for any part of the quartz content in these rocks. Such mineralogic and textural similarity implies consanguinity, probably best explained by the hypothesis that these rocks crystallized serially from magmas derived from a common source.

The primary minerals of the igneous rocks are plagioclase, microcline, quartz, biotite, hornblende, allanite-epidote, monazite, magnetite, zircon, and apatite. The secondary minerals, products of deuterie alteration and of weathering, are magnetite, myrmekite, clinozoisite-epidote, garnet, penninite, sericite, albite, sphene, pyrite, clay, limonite, and carbonate.

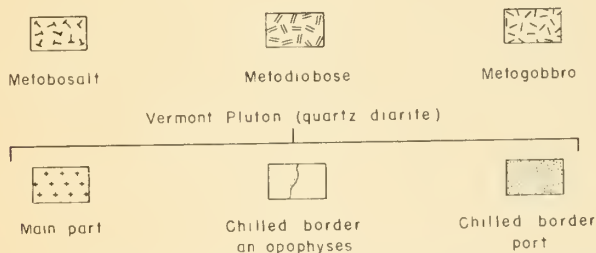
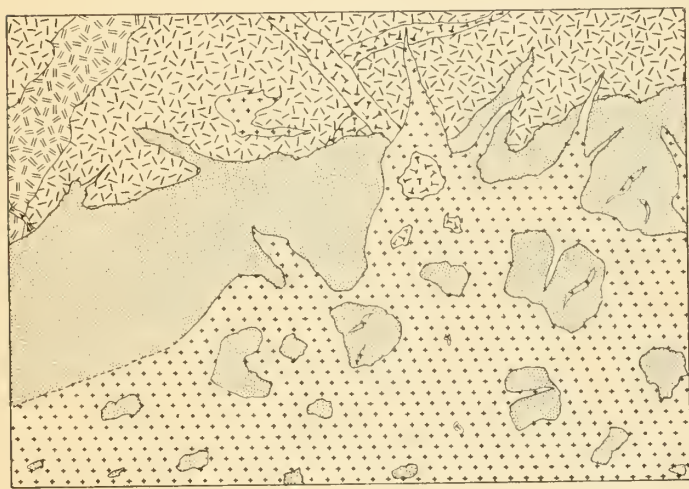


Figure 4. The nature of the contact zone of the Vermont pluton and metamorphosed basic igneous rocks. Composite sketch from roadcuts along Griffith Park Road, Mt. Hollywood block, Griffith Park.

Vermont Quartz Diorite

The Vermont pluton,* which is composed of quartz diorite, is intrusive into the metamorphosed gabbro-diorite-basalt complex that comprises the faulted remnants of a roof pendant in the central part of the Mount Hollywood block. The pluton consists of two homogeneous textural parts, a medium-grained part—called the main part

—and a fine-grained chilled border part. The main part contains inclusions of the chilled border part. Dikes of aplite and pegmatite are common in the pluton and in the metamorphic rocks.

The contact between the metamorphic rocks and the Vermont pluton is a wide zone that is divisible into a zone of apophyses and a zone of inclusions. The chilled border part of the Vermont pluton is a discontinuous mass around the roof pendant. The chilled border and the metamorphic rocks on the periphery of the pendant are veined by irregular apophyses of quartz diorite that range in width from an eighth of an inch to several feet. A chilled border, as much as 2 inches thick, is found along the sides of these apophyses.

The zone of apophyses passes insensibly into a zone of inclusions that comprise the remainder of the exposed part of the Vermont pluton. The size and abundance of inclusions decreases away from the roof pendant; numerous inclusions, averaging one foot in diameter, are present in all of the exposures of the pluton. Most of the inclusions are fragments of the chilled border, but a few fragments of the metamorphic rocks are also included. The quartz diorite shows no textural changes in the vicinity of the inclusions. A few fragments of the included chilled border rock are metamorphosed.

Petrography. In most exposures the chilled border rock is fresh, light gray, and fractured. Where weathered the rock is friable and almost black. Most of the chilled border is massive. In places, flow structures are present due either to 1) parallel discoid aggregates of biotite crystals, or 2) subparallel tabular plagioclase crystals. The texture is uniformly hypautomorphic, fine-grained and equigranular. The ferromagnesian minerals in the metamorphosed specimens are xenoblastic and poikiloblastic. Mineralogically, the chilled border part is like the main part of the pluton. The metamorphosed specimens of the chilled border rock contain more hornblende (5 percent) and biotite (10 percent). The additional biotite and hornblende may have been introduced by the enclosing magma. The other minerals of the rock are unchanged.

The main part of the pluton forms the north side of the Mount Hollywood block. Most exposures are weathered light rust-brown; each grain of the rock is coated with a thin film of limonite. The fresh rock is dark gray and usually fractured; the fractures are coated with limonite. The structure appears to be massive in outcrop; an ill-defined flow structure is visible on polished surface and is due to a crude parallelism of discoidal aggregates of unoriented biotite crystals. The texture is hypautomorphic, equigranular, and medium-grained. Along the borders of apophyses and in places along the thick chilled border part, the main part grades into the chilled border within less than an inch.

Aplite and Pegmatite Dikes. Aplite and pegmatite dikes are numerous in the contact zone and in the metamorphic rocks. Such dikes are common in the central part of the pluton. Most of the dikes are aplite; a few small granite pegmatite dikes are present.

The dikes are light cream-colored. The rock is fairly resistant to weathering, and crops out above the enclosing rocks. Most of the aplite dikes are sheared along their borders, and, to a lesser extent, within the bodies of the dikes.

* Pluton is a term, coming into more general use, which includes various bodies of igneous rock formed by slow cooling, particularly where the form of the rock body is irregular or unknown. *Ed. note.*

The texture is fine-grained xenomorphic, inequigranular; pegmatites are coarse-grained and have a xenomorphic texture with patches of graphic texture. The composition ranges from quartz monzonite aplite to granite aplite.

Petrogenesis. Intrusion of the Vermont pluton apparently was in two stages. The first is represented by a thick chilled border on the periphery of the roof pendant of metamorphic rocks. No evidence exists as to the mode of intrusion during the first stage; the presence of magmatic currents during this stage is indicated by the flow structures in some specimens of the earlier chilled border rocks.

The second stage of intrusion is represented by the transgression of the earlier chilled border. Flow structures indicate the existence of magmatic currents during this stage also. The following features are excellent evidence that the second stage of intrusion was by means of stoping: 1) veining of the metamorphic rocks and of the earlier chilled border rocks by apophyses; 2) blocks of wall-rock that are nearly pried loose; and 3) the abundance of inclusions.

No evidence of chemical assimilation is present. Inclusions have knife-sharp contacts with the quartz diorite, and the mineralogy and texture of the inclusions show no relation to the contact with the quartz diorite. Furthermore, most of the inclusions differ in no wise from the same rocks where present in the roof pendant.

The thin chilled borders on the apophyses of the second stage of intrusion and the lack of a chilled border of quartz diorite around inclusions demonstrate that the country rock during the second stage of the intrusion had a temperature only slightly less than that of the magma. On the other hand, the thick chilled border of the first stage of intrusion reflects a large temperature difference between the wallrocks and the magma. The evidence for a higher temperature of the country rock during the second stage of intrusion gives reason to suggest that the greater part of the metamorphic changes in the basic igneous rocks happened during this stage of intrusion.

Quartz Diorite

The Lar pluton, composed of quartz diorite, is exposed in the Riverside block (pl. 1), where it is intruded by albite and by basalt dikes. Inclusions of quartz diorite in the Feliz pluton in the Mount Hollywood block and the quartz diorite microbreccia in the Cahuenga Peak block may be parts of the Lar pluton.

Petrography. Most outcrops of this quartz diorite are deeply weathered and white. Three textural varieties of the Lar pluton are mapped in the Riverside block: 1) a well foliated quartz diorite (foliated part), characterized by biotite aggregates; 2) a poorly foliated to massive, even fine to medium-grained quartz diorite (massive part); and 3) an even-textured, well-foliated rock (sheared part) that contains zones of mylonite and microbreccia parallel to the foliation.

The contacts between the foliated and massive parts are gradational in distances of 1 to 6 inches. The structural relations of these parts, both on large and on small scale, consist of interfingering sheets of quartz diorite. In places, the foliation is swirled.

The texture of the foliated part is xenomorphic-hypautomorphic. Ragged tabular oligoclase crystals are poorly oriented with their broad faces subparallel to the plane of foliation. The foliation is primarily a reflection of disc-shaped aggregates and bands of biotite; the biotite crystals of these aggregates do not have a preferred orientation. The texture of the massive variety of quartz diorite is hypautomorphic-xenomorphic. Biotite crystals are evenly distributed. The gradation between the two parts consists of a rapid decrease in the proportion of biotite that is aggregated.

The texture of the sheared part is xenomorphic-oriented; ragged tabular oligoclase crystals and irregular anhedral elongated quartz grains and groups of quartz grains show a marked parallelism. Most, but not all, biotite crystals are also oriented; the crystals show a space-filling habit in part; some crystals are bent. Rocks of this part do not contain biotite aggregates. Thin zones of mylonite and thick zones of microbreccia, which contain sheared inclusions are present. These zones are commonest along the south edge of the Riverside block. By decrease in perfection of mineral shape-orientation and by lessening of the intensity of fracture, the sheared part grades into the other parts. The sheared part is hydrothermally altered, with the extensive development of chlorite, epidote, and sericite.

Inclusions. Inclusions are rare in the Lar pluton. Two mineralogic varieties are present. The texture of both types is granoblastic and poikiloblastic. Melanocratic inclusions are composed of 15 percent hornblende, 20 percent biotite, 20 percent quartz, and 45 percent plagioclase. Leucocratic inclusions contain 25 percent microcline, 20 percent plagioclase, 30 percent quartz, 20 percent biotite, and 5 percent hornblende. All inclusions are disc-shaped and are parallel to the flow structure of the pluton.

Associated Dikes. A few short, thin alaskite dikes are present along planes of foliation on the north side of the Riverside block. They have a xenomorphic, coarse- and fine-grained texture.

Fragments of white, fine-grained, xenomorphic meta-aplite are present in a few places in microbreccia zones in the sheared part. The rock consists of thin bands of partly recrystallized microbreccia and of protomylonite. The composition is 60 percent quartz, 30 percent clinzoisite, 9 percent zoisite, and 1 percent penninite.

Quartz Diorite Inclusions in the Feliz Pluton. These inclusions are correlated with the Lar quartz diorite, because of the similarity of the mineral composition and of the texture of the two rocks. These inclusions, like the Lar pluton, are intermediate in composition between the other two intrusives.

The inclusions range from a few inches up to 500 feet or more in diameter. They are scattered throughout the Feliz pluton, and are more abundant than is indicated on the geologic map (pl. 1). The contact between the inclusions and the Feliz pluton are sharp. The outlines of the inclusions are jagged and irregular; they appear to have been controlled by joints in the quartz diorite inclusions. The structure of the inclusions is massive, and the texture is hypautomorphic, equigranular, and fine-grained. A few thin zones of microbreccia are present.

Microbreccia of Lar(?) Quartz Diorite. The microbreccia in the Caluenga Peak block is correlated with the Lar pluton for the same reasons that the quartz diorite inclusions in the Feliz pluton are correlated with the Lar pluton.

The rock is a coarse-grained macrobreccia, with numerous intersecting zones of microbreccia. The breccia is traversed by subparallel planes of gouge, along which the breccia has been chloritized. These shear zones are later than the brecciation; they offset aplite dikelets that intruded and metamorphosed the breccia. The quartz diorite in the northern half of the exposure is more intensely brecciated and finer grained than that in the southern half of the exposure. The hypautomorphic, equigranular, and fine-grained texture of the quartz diorite is well preserved in small fragments. The minerals are only slightly altered, hardly more so than in the non-brecciated igneous rocks in this area. Fragments of vein quartz are present in a few places.

A few small thin dikelets of quartz diorite aplite are intrusive into the microbreccia. No evidence of their origin is available. The dikelets are surrounded by thin aureoles of altered breccia. The aplite is hypautomorphic, equigranular, and fine to medium-grained. Plagioclase, 50 percent of the rock, is altered to sericite and albite. Quartz (35 percent), biotite (replaced by chlorite, 10 percent), and hornblende (pseudomorphosed by carbonate, 5 percent) comprise the rest of the rock.

Adjacent to the dikelets, the microbreccia is replaced by feathery aggregates of phengite(?) and by irregular patches and veinlets of carbonate. Plagioclase is albitized, and quartz is partly replaced by phengite(?). Phengite(?) comprises the rest of the rock (40 percent). The original cataclastic texture is almost obliterated.

Origin of Foliation. Two kinds of foliation are present in the Lar pluton. The zones of brecciation and mylonitization are a kind of foliation that is the result of shearing of a solid rock. This cataclasis may have happened shortly after crystallization of the magma and before the rock had completely cooled. This is suggested by 1) parallelism of the zones of cataclasis with foliation of the quartz diorite; 2) the extent of the hydrothermal alteration, which is much more intense than that of the microbreccias elsewhere in this area; and 3) the texture of the sheared part of the pluton.

The foliation of the foliated part and the much poorer foliation of the massive part probably is the result of laminar flow during intrusion, as suggested by the following observations:

- 1) Disc-shaped aggregates of biotite, but not single crystals, have a preferred orientation. If due to shearing of a solid rock, the biotite crystals should be oriented.
- 2) In places the foliation is swirled.
- 3) Tabular oligoclase crystals are parallel.
- 4) The contacts between the foliated and the massive parts are gradational and the two parts have irregular, interfingering contacts. Small, discoidal schlieren of the foliated quartz diorite are enclosed in and parallel the poor foliation of the massive part.
- 5) Inclusions and alaskite dikes parallel the foliation.

Mode of Intrusion. The structure of the Lar pluton and its differences in composition can be explained as the result of serial injections of magma closely spaced in time. Each successive injection took place before the

preceding injection had completely crystallized. If differentiation was taking place during the period of intrusion, the order of intrusion would be 1) massive part, 2) foliated part, and 3) sheared part, assuming intrusion to be in the order of decreasing alkali-content. This sequence is also indicated by the finer grain of the massive rock relative to the other parts, assuming the finer grain to be indicative of chilling, as in the Vermont pluton.

Continuation of stress conditions in the sheared part during and after final crystallization may have produced the zones of brecciation and mylonitization. The concentration of the effects of shearing in the southern part of the exposure gives reason to suggest an origin of the Griffith block in the stress pattern that caused the foliation of the Lar pluton, in the Riverside block. The contact between the Lar pluton and the Vermont pluton, under the sediments in the Griffith block, may have been a wide fault zone in its final stages of development, ending up as the Griffith block.

Feliz Granodiorite

The Feliz pluton, which is composed of granodioritic rocks, is exposed in Griffith Park in the Mount Hollywood block (pl. 1) and for a short distance in the foothills south of Los Feliz Blvd., where it is buried under Tertiary sediments. The granodiorite microbreccia in the Griffith block is probably part of the Feliz pluton. The Feliz pluton appears to be intrusive into the Vermont pluton and into the metamorphic rocks.

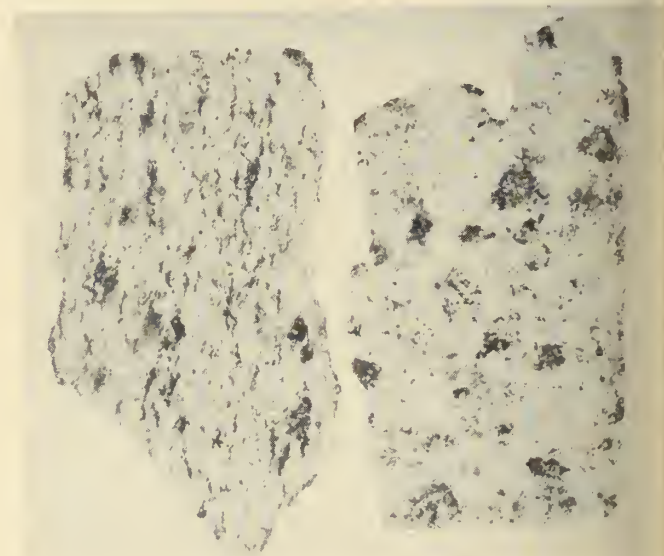


Figure 5. Discoidal biotite aggregates in the foliated part of the Lar biotite quartz diorite. Natural size. Photo by John De Gross, 195.

The contact of the Feliz pluton with the Vermont pluton and with the metamorphic rocks is exceedingly irregular in detail, but in general, it is a fairly straight line (pl. 1). Along the contact, rocks of the Feliz pluton and the older rocks are brecciated; shear zones in the older rocks are subparallel to the contact. No texture or mineralogic changes, related to the contact, are present in the granodiorite or in the older rocks.

Petrography. Outcrops of the Feliz granodiorite are deeply weathered, friable, and white; fresh rock was

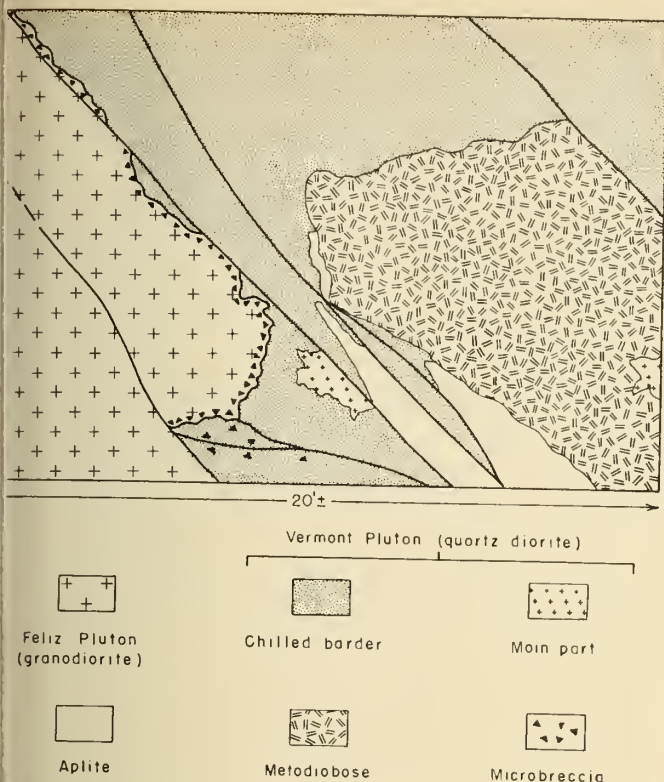


Figure 6. The contact of the Feliz and Vermont plutons and associated metamorphosed basic igneous rocks. Sketch from roadcut along Vista del Valle Drive, Mt. Hollywood block, Griffith Park.

and in only one place. The structure is massive. The texture is hypautomorphic-monzonitic, equigranular, and fine to medium-grained. The intrusive is heterogeneous; large, vaguely outlined, subrounded masses—having dimensions on the order of hundreds of feet to hundreds of yards—of a finer grained variety are enclosed in a thick

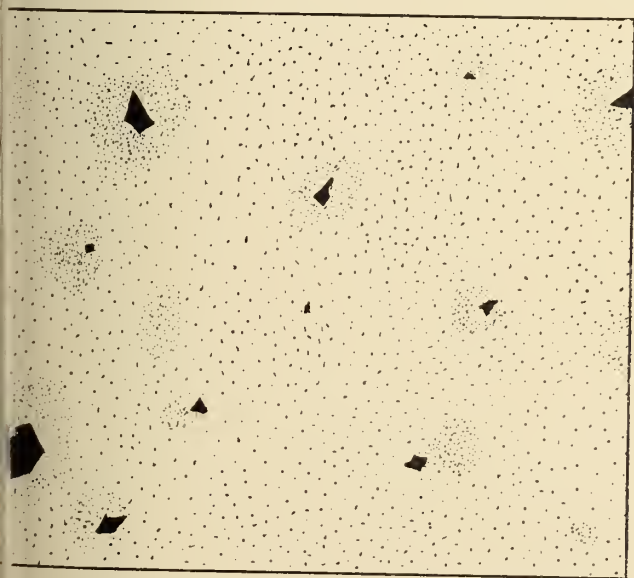


Figure 7. Schematic diagram of the 'web and inclusion' structure caused by variations in the grain size and in the mineralogical composition of the Feliz granodiorite.

web of a coarse-grained variety (figure 7). The variation in grain size appears to show a spatial relation to the quartz diorite inclusions, but not to the contact with the older rocks; that contact transgresses the web-structure of the Feliz pluton.

The amount of microcline shows a close relation to grain size; it is most abundant in the coarser grained parts. The rocks of the pluton range from biotite quartz diorite to biotite quartz monzonite; the mean composition of the pluton seems to be that of a biotite granodiorite.

Along pre-Miocene faults, the granodiorite is sheared into alternating bands of mylonite and protomylonite in zones ranging from half an inch to 30 feet in thickness. Slickensides and mullion structure are spectacularly developed.

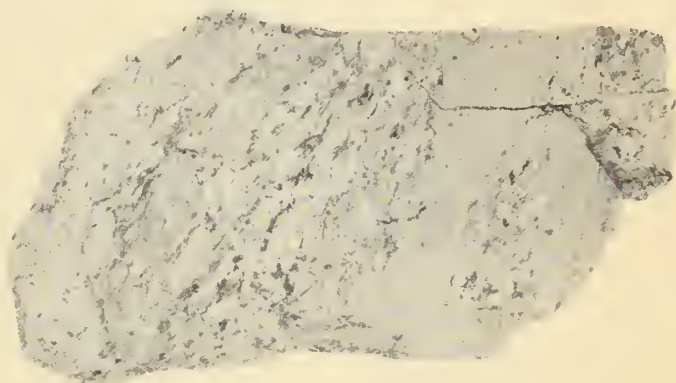


Figure 8. Protomylonite structure along some of the faults in the Feliz granodiorite.

A few small inclusions of mafic rock are present in half a dozen places in the pluton. They have a granoblastic texture and consist chiefly of biotite and hornblende. Presumably they are fragments of the older metamorphic rocks.

Aplite Dikes. A very few, small, irregular dikes of aplite are present in the Feliz pluton; they are derived probably from the magma from which the Feliz pluton crystallized. The texture varies irregularly from xenomorphic to hypautomorphic, inequigranular, and from fine to medium-grained. The dikes are quartz monzonite aplite.

Microbreccia of Feliz (?) Granodiorite. A small fault block of hydrothermally altered granodiorite microbreccia is exposed in the western end of the Griffith block. No evidence exists to prove that this rock is present under the sediments throughout the extent of the Griffith block, but such an assumption seems reasonable.

The rock is deeply weathered in all exposures, and is light greenish-white. Thin, intersecting zones of microbreccia and of mylonite traverse this microbreccia. The zones have no preferred orientation. The texture is cataclastic; a few aggregates of broken grains suggest a former monzonitic texture.

One small, white aplite dike was found in this breccia. It consists of alternating bands of microbreccia and of protomylonite. The minerals are 45 percent plagioclase (albitized), 50 percent quartz, 3-4 percent orthoclase, and a small amount of epidote. Small stringers of orthoclase form a cement for the other minerals of the rock.

Mode of Emplacement. The presence of large inclusions of quartz diorite (Lar ?) in the Feliz pluton in the Mount Hollywood block gives reason to suggest that the mode of intrusion in this block, at least in part, was by stoping. Intrusion of part of the pluton may have localized along the Griffith block, and subsequently brecciated and subjected to hydrothermal alteration.

The contact of the Feliz pluton with the Vermont pluton and its roof pendant of metamorphic rocks has the following unusual characteristics.

- 1) The overall contact is a relatively straight line.
- 2) In detail, the contact is an irregular, sutured boundary.
- 3) A zone of granulation is present on both sides of the contact, but the granulation is more intense in the granodiorite.
- 4) Shear planes are confined to the older rocks.
- 5) The older rocks show no metamorphic changes that might have resulted from intrusion of the Feliz pluton.
- 6) The compositional and textural variations in the Feliz pluton show no relation to the contact.
- 7) Structures of the rock masses on both sides of the contact are truncated along the contact.
- 8) The contact is parallel to the foliation in the Lar pluton, and to the trend of the Griffith block. (This is the regional strike of the basement rock structures of the Santa Monica Mountains and of the surrounding mountains of the Transverse Ranges.)

The contact shows features both of fault and of intrusive contacts. Possibly it is a fault contact formed when the granodiorite was nearly, but not wholly, crystalline. The lack of metamorphic effects attributable to the granodiorite magma suggests that the rock was relatively cold at the time of intrusion. The lack of shear planes in the granodiorite and the granulation that gradually disappears a few feet from the contact are the basis for suggesting a partly fluid magma at the time the contact was formed; had it been solid, shearing analogous to that in the older rocks might be expected. Drag by such a viscous magma along the cold, older rocks may have been the mechanism — i.e., plucking — that caused the suturing of the contact. Fragments of the older rocks should be present in the granodiorite, if the suggestion is correct, but they were not found. The magma may have been too nearly solid to readily incorporate such fragments or they may have been removed from the region of the fault that is now exposed.

Crystallization and Differentiation. The web structure of the pluton is an unusual feature, whose explanation may be as follows. Large inclusions of cold wallrock (quartz diorite), on being incorporated in the magma, caused the surrounding magma to begin to crystallize sooner and more rapidly than the magma that was free of inclusions. After the inclusions had been sufficiently warmed and after crystallization had progressed sufficiently far to determine the final texture and mineral composition of the adjacent magma, some of the inclusions may have risen or have sunk in the magma and thus have produced the present partly irrational distribution of the inclusions. The earlier and more rapid crystallization of magma surrounding the inclusions should have caused a concentration of plagioclase relative to microcline—the last mineral to crystallize—and a finer grained texture; the coarser grained parts of the pluton have a higher microcline content than the finer grained parts. That such a pronounced influence by these inclusions is possible seems reasonable in view of their large mass.

Hypabyssal and Extrusive Igneous Rocks

Numerous dikes, sills, irregular shallow intrusive bodies, flows, agglomerates, breccias, and tuffs are present in the Griffith Park area. The rock types are, in order of abundance, augite basalt, olivine basalt, malchite, alkali trachyte tuff, and andesite porphyry. The malchite and the andesite porphyry are pre-Cretaceous intrusives. The basaltic rocks comprise perhaps the greatest bulk of the lower member of the middle Miocene Topanga formation in this area.

A single dike of andesite porphyry is present in the quartz diorite microbreccia in Brush Canyon. Malchite dikes are confined to the Riverside block in this area, but are common in the basement rocks of the Santa Monica Mountains west of Cahuenga Pass. Basalt dikes are most abundant in the western end of the Riverside block and in the eastern end of the Mount Hollywood block. A few basalt dikes are present in the quartz diorite microbreccia in Brush Canyon. Sills and irregular intrusives of basalt and extrusive basaltic rocks are most abundant in the Ferndell and Mount Hollywood blocks and in the Cahuenga Pass block. A few small sills of basalt are intrusive into the other sedimentary rock units in the Griffith Park area.

Malchite. Numerous malchite dikes are intrusive into the Lar pluton in the Riverside block; they are present nowhere else in this area. The dikes are strikingly similar to the pre-Cretaceous malchite dikes west of Cahuenga Pass (Neuerburg, 1951c). Because of a similarity of unusual petrologic characteristics, as well as a similar restricted occurrence to basement rocks, the malchite in the Riverside block is considered to be also of pre-Cretaceous age.

The dikes range in thickness from 1 foot to 30 feet. The rocks are massive. Textures range from very fine-grained felted in chilled borders and in thin dikes through panautomorphic to porphyritic-panautomorphic. Fresh specimens are dark bluish gray; weathered rocks are cream white.

Phenocrysts consist of augite and andesine. The essential minerals are andesine (typically much altered) and kaersutite (?) (titaniferous hornblende—Campbell and Schenk, 1950, p. 682). Titaniferous magnetite and apatite are the minor accessories. Augite is present in some specimens. Abundant clinozoisite, chlorite, and carbonate are space-filling elements in the rock fabric. The very fine-grained varieties of these dike rocks apparently consist of albitized andesine, augite, and intragranular chlorite with some titaniferous magnetite and, in some specimen, pyrite.

Andesite Porphyry. A small dike of blue-gray andesite porphyry is intrusive into the quartz diorite microbreccia in the Cahuenga Peak block. Fragments of the rock are present in the overlying Cretaceous (?) sedimentary breccia and conglomerate (Cahuenga beds). The rock consists of white andesine phenocrysts set in a fine-grained matrix of felted oligoclase crystals and intragranular elements consisting of apatite, quartz, biotite, magnetite, penninite, epidote, and calcite.

Basalt. Dark brown and red-brown intrusive and extrusive bodies of basalt comprise the major part of the lower member of the Topanga formation. Extrusive basalt is confined to this member. The exposures of basalt

and sediments in the quarry on the east side of Brush Canyon (in the Ferndell block) show well the complex structure of the basalt and sediments. Apparently deposition of sediments and accumulation of pyroclastic basalt terminated and produced interbedded and interfingering units; intrusions of basalt occurred repeatedly throughout the entire period of deposition of the lower member of the Topanga formation. An unusual inclusion structure typical of this member in the Ferndell block: fragments of sediments, agglomerates, flow breccias, flows, and earlier intrusives comprise a chaotic jumble of inclusions within masses of intrusive basalt. This structure is repeated on a smaller scale in places in the Mount Hollywood block.

The abundant dark brown extrusive basalt consists mostly of coarse-grained agglomerate. A few thin pillow lava flows are present in places in the Mount Hollywood block; a pillow lava about 50 feet thick occurs near the top of the lower member of the Topanga formation in the Cahuenga Pass block. No massive flows of basalt were recognized, although such are present on the west side of the Cahuenga Pass. The extrusive basalt is usually not vesicular. All forms of basalt are deeply weathered to a light brown, clayey mass.

Dikes of basalt in the Feliz pluton have parallel sides. The structure is massive and chilled borders are present. A single large pipe-like intrusive in the easternmost exposure of the pluton is surrounded by a swarm of thin basalt dikes. Elsewhere in the pluton, dikes are uncommon. It appears likely that this pipe was a feeder to a volcano. A swarm of highly irregular, thin dikes of dark brown basalt are present in the Lar pluton in the Riverside block; the dikes are most numerous in the western end of the block. The irregular shape is probably due to joints and fractures in the quartz diorite. Thin dikes of dark brown basalt, along shear planes, are present in the quartz diorite microbreccia in Brush Canyon.

Small sills of basalt are present in all of the sedimentary formations. Large sills and irregular intrusive bodies of dark brown basalt are common in the lower member of the Topanga formation. Many of these intrusives are amygdaloidal; the distribution of the amygdules is erratic and appears to have no relation to contacts or to inclusions. Veins of zeolites and related minerals are common in these intrusive rocks. The texture ranges from porphyritic and intergranular to intergranular; most specimens of intrusive rock are porphyritic. Phenocrysts generally comprise about 10 percent to 15 percent of the rock; the minerals are andesine-labradorite, augite, and in some specimens olivine. The groundmass consists predominantly of andesine with a little augite and magnetite; chlorite and chlorphaeite (?) fill spaces in the groundmass. Corroded and broken xenocrysts of plagioclase and quartz occur in a few specimens.

The earliest and the most abundant zeolite is analcite. Associated minerals are natrolite, heulandite, apophyllite, thomsonite, calcite, and prehnite. These minerals occur as amygdules, vein fillings, and as selvages along the borders of pillow basalts. The central parts of crystals of plagioclase in all the specimens of basalt that were examined are replaced by jagged patches of analcite and by a little albite. Between one-quarter and one-third of the plagioclase is replaced by analcite. The large amount of analcite in the basalt and in cavities in the

basalt suggests an excess of soda in the basaltic magma and lava. Such an excess of soda appears to be a characteristic feature of all Tertiary basalt and diabase in the Santa Monica Mountains (C. Durrell, personal communication).

More than three-fourths, by volume, of the intrusive basalt in the Santa Monica Mountains, east of Topanga Canyon, is present in the Griffith Park area, and most of that in the Ferndell block. From this single fact, it seems likely that the Ferndell block was a major volcanic center during the middle Miocene.

Flow Breccia. Numerous small inclusions and a few "beds" of a distinctive red flow basalt apparently represent a stratigraphic marker in the lower member of the Topanga formation. The rock is resistant to weathering and crops out above the enclosing basalt. It consists of flow breccia, bedded tuff, and scoriaceous flows. The texture is intergranular or intersertal. The groundmass consists of dark red, nearly opaque chlorphaeite (?). Angular to subangular fragments of crystals of augite, analcitized and albitized andesine, and basalt are set in this groundmass. Many of the fragments in the breccia are vesicular; some of the vesicles in the fragments and in the scoriaceous flows contain a small amount of analcite, natrolite, and chlorite.

Alkali Trachyte Tuff. Beds of alkali trachyte tuff, 10 to 15 feet thick, occur in the lower and upper members of the Topanga formation. Casts of small pelecypods show that the beds were deposited in the sea. The beds in the upper member are light cream tuff and gray, sandy impure tuff, interbedded with silty clay shale and arkose; those in the lower member are inclusions in basalt. The tuff is very fine-grained, massive, and much fractured. Laths of albite-oligoclase are the most abundant components of the rock. A very few grains of quartz and fragments of alkali trachyte comprise the remainder of the rock.

Boulders of alkali trachyte are present in the basal conglomerate of the Holycrest formation. Hoots (1931, p. 101) mentions the occurrence of trachyte dikes of probable middle Miocene age in the western part of the eastern Santa Monica Mountains. It seems likely that the alkali trachyte tuff represents an extrusive facies of the trachyte dikes in the Santa Monica Mountains, west of this area. Similar tuff beds are noted by Terpening (1951) on the west side of Cahuenga Pass.

Geologic History

Order of Plutonic Intrusion. No unequivocal direct evidence of the sequence of intrusion of the plutonic rocks of this area is available. The sequence is postulated to be as follows: Vermont pluton, Lar pluton, and Feliz pluton. This sequence is based on two assumptions: 1) the rocks of the three plutons are consanguineous and were derived serially from the same parent magma; and 2) the spatial relations of the three plutons is essentially the same as it was during the period of intrusion.

Aplite dikes are very abundant in the Vermont pluton, whereas they are rare in the other plutons. The aplites of Vermont pluton contain much potash feldspar in strong contrast to the aplites of the other plutons. This distribution is readily explicable if the Vermont pluton

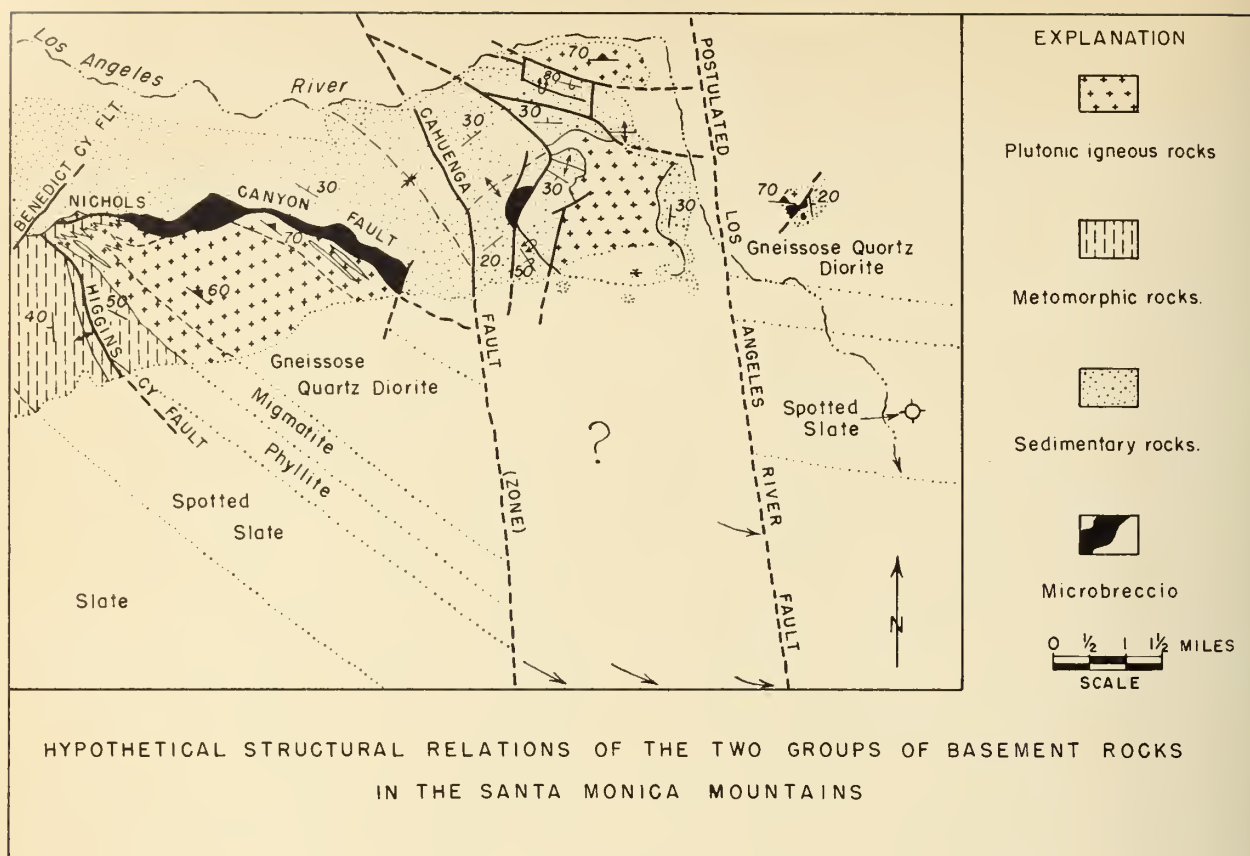


Figure 9.

be the oldest. The nature of the contact between the Vermont and Feliz plutons, interpretive as it must be, is further indicative of the older age assigned to the Vermont pluton.

The remainder of the sequence follows from the assumption of a serial derivation of the magmas from a common source. The Lar pluton is compositionally intermediate between the other two and accordingly is logically expected to be intermediate in age. The inclusions of quartz diorite in the Feliz pluton are, like the Lar quartz diorites, intermediate in composition between the rocks of the Feliz and Vermont plutons, and it seems likely that they are parts of the Lar pluton, enclosed in the younger Feliz pluton.

Age. The age of the basement rocks in this end of the Santa Monica Mountains is not known. They are older than Upper Cretaceous if the Cahuenga formation in the area is Upper Cretaceous as has been suggested by Dr. D. Axlerod (personal communication). The rocks are not like the pre-Cretaceous(?) basement rocks in the rest of the Santa Monica Mountains and in Forest Lawn; they are separated from all other basement rocks by faults of large displacement (Neuerburg, 1951b). Also, they are present in a structurally and stratigraphically discordant geologic element in the Santa Monica Mountains. The possibility that these rocks are in an exotic block, brought to this geographic position from some other place, must be entertained, for it is impossible to fit them into the local basement rock geology (Neuerburg, 1951c).

SEDIMENTARY ROCKS

Three Tertiary formations and two possibly Cretaceous units are present in the Griffith Park area. These are the Modelo formation, Hollycrest formation, Topanga formation, Cahuenga beds, and Griffith beds. The petrography and the maximum thickness of each unit and its subdivisions are presented in table 1 and in figure 10. Each is a major stratigraphic unit in the Griffith Park area. All but the Griffith and Cahuenga are present in the Santa Monica Mountains west of Cahuenga Pass, but the rocks and structures of these formations in the Griffith Park area differ in some respects from the rocks and structures of the same formations west of Cahuenga Pass. These differences appear to be the result of local conditions of deposition that reflect the movement of major fault blocks during the accumulation of these sedimentary rocks.

The areal distribution of the sedimentary rocks is a unique pattern that reflects the major basement structure of the Griffith Park area (pl. 1 and fig. 10). The thickest accumulations are exposed in three fault blocks that appear to have been the troughs of major deposition. The Cahuenga beds occur principally in the Cahuenga Pass block; remnants of this unit are present in the Ferndell and in the Griffith blocks. The greatest thickness of the Topanga formation is in the Ferndell block and in the Mount Hollywood block on the south side of the Griffith block. An appreciable thickness of the Topanga formation is present in the Cahuenga Pass block, but this part of the Topanga formation is the easternmost extension of the

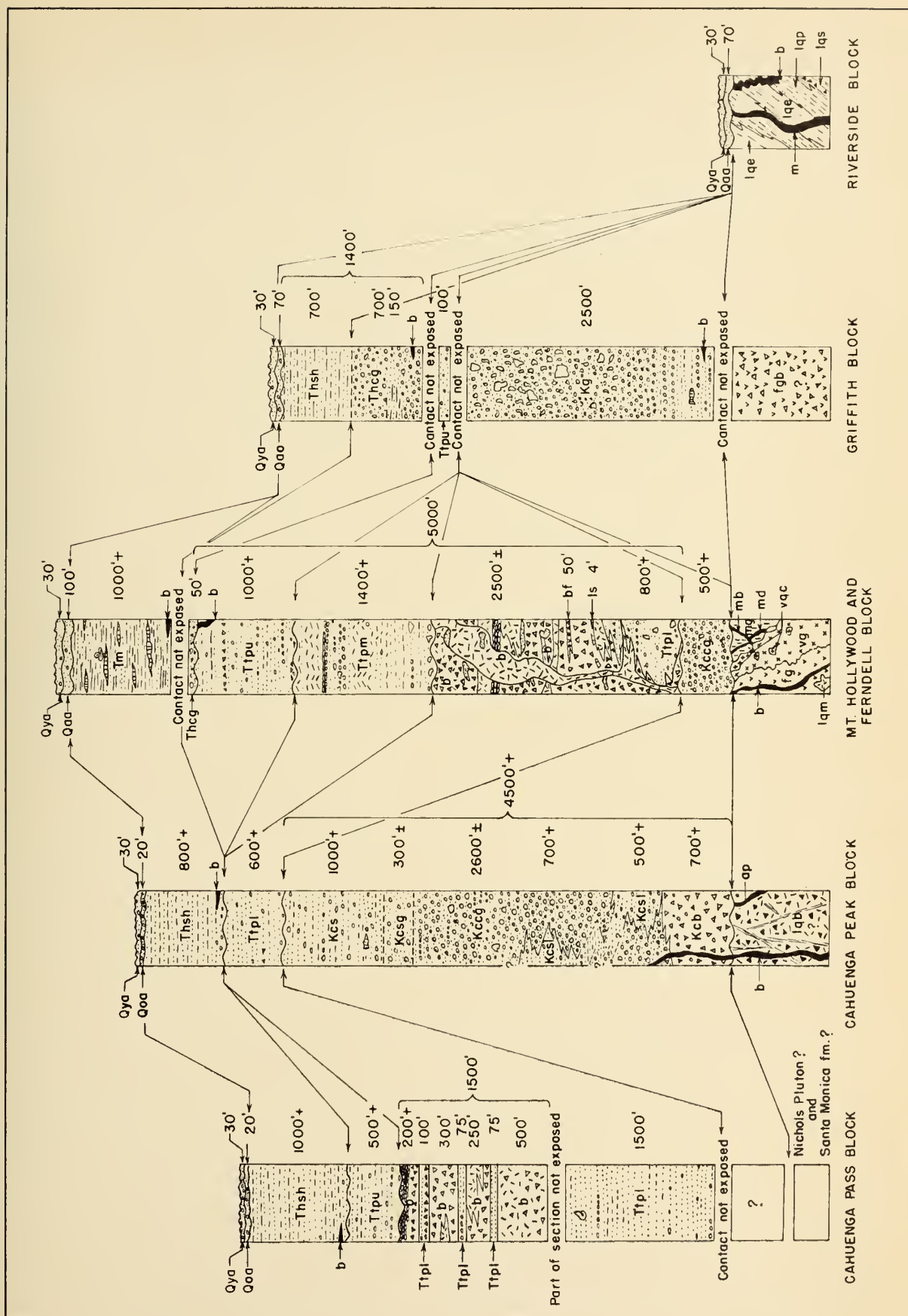


Figure 10. Columnar sections in each of the fault blocks of the Griffith Park area.

more typical rocks of the Topanga formation west of Cahuenga Pass; the deposition of this part of the formation appears to have been independent of the fault block structure of the Griffith Park area. The conglomeratic member of the Hollycrest formation is present only in the Griffith block; thus it appears to be the product of local conditions of deposition. The Hollycrest formation, in the Cahuenga Pass and in the Cahuenga Peak blocks, extends westward to Coldwater Canyon (Terpening, 1951 and Truex, 1950), but does not seem to be present elsewhere in the Santa Monica Mountains. Its deposition appears to have been independent of the fault block structure of the Griffith Park area—except for the basal conglomerate.

Three conglomerate beds are mapped: 1) Griffith beds; 2) Cahuenga beds; and 3) the lower member of the Hollycrest formation. They are easily separable in the field because of the differing lithology of the boulders contained in them. The granitic conglomerate of the Griffith beds contains abundant fragments of metamorphic rocks and of rocks that may be identified with outcrops in the Verdugo Hills, on the north side of San Fernando Valley. The source area of the rock types in the conglomerates of the Cahuenga and Hollycrest formations is not known. These conglomerates contain almost no metamorphic rocks. The granitic conglomerate of the Cahuenga beds has abundant pebbles and cobbles of acid porphyries and boulders of a unique vesicular basalt. The conglomerate of the Hollycrest formation contains principally boulders of various granitic rocks and little else.

Cretaceous (?) Rocks

The oldest dated sedimentary rocks in the Santa Monica Mountains are Upper Cretaceous in age (W. P. Popenoe, personal communication). Such rocks comprise the so-called Chico formation, which crops out in isolated fault blocks in the Santa Monica Mountains. The Chico formation is largely a granitic boulder conglomerate containing abundant pebbles and cobbles of acidic porphyries, which serve to distinguish it from other boulder conglomerates in the Santa Monica Mountains. Except for the lower member of the Hollycrest formation, no granitic boulder conglomerates, younger than the Cretaceous, are known in these mountains. Principally for this reason, the Cahuenga beds in the Griffith Park area are assigned to the Cretaceous; correlation with the Chico formation is not suggested because of differences in detailed lithology.

For the same reason, the Griffith beds are tentatively assigned to the Cretaceous. Structural evidence indicates that this unit is older than the Cahuenga beds. Two or three boulder conglomerate formations underlie the "Chico" formation in the Santa Monica Mountains west of this area. A red boulder conglomerate, probably a correlative of ???, (Terpening, 1951; Truex, 1950), crops out in small patches along the basement contact from Cahuenga Pass to Stone Canyon. In Nichols Canyon (Terpening, 1951) near the Encino Reservoir (Neuerburg, 1951c), and in Forest Lawn are pre-Chico granitic boulder conglomerates that have been derived almost entirely from the underlying basement rocks. None of the Chico and pre-Chico conglomerates seem to be likely lithologic correlatives of the Griffith or of the Cahuenga beds.

Unfortunately, the general absence of invertebrate fossils in the pre-Tertiary sediments of the Santa Monica Mountains and the isolated occurrences of the rocks do not lend encouragement to the hope that their stratigraphy will be elucidated. Fish scales in the Cahuenga and Griffith beds offer some hope, once the use of fish scales for age determinations of early and pre-Tertiary formations are adequately documented.

Griffith Beds

The Griffith beds are exposed in a fault block within and near the eastern end of the Griffith block. The unit is in fault contact with sediments of the Topanga and Hollycrest formations on all sides. On the basis of lithology, the beds are separable into four units or members not separately mapped because of lack of exposures. The lowest member, about 500 feet thick, consists predominantly of thick-bedded medium-grained arkose with thin beds of silty clay shale, siltstone, and pebble conglomerate. The second member consists of thick beds of cobble conglomerate and of arkose; a few thin beds of platy, sandy shale are present. This member is about 150 feet thick. The third and fourth members are not easily separated; both members are composed of boulder conglomerate. The third member has about 20 percent arkose matrix as compared to 30 to 40 percent in the fourth member. The fourth member shows much variation in grain size, whereas the size of the boulders in the third member is more uniform.

The arkose is massive, medium to coarse-grained, and angular to subangular. Small rock fragments are abundant. The cement is calcite. The massive arkose and the arkosic matrix of the conglomerates are weathered to a soft, friable, yellow brown mass; the fresh rock is greenish gray. Thin-bedded, white to tan silty clay shales are interbedded with thin beds of siltstone and of fine and medium-grained arkose. Fish scales are uncommon in the shale; they are evidence for calling the two lowest members marine.

The boulders are subangular to rounded and have rough surfaces. Boulders 3 and 4 feet in diameter are common in the fourth member. About 70 percent of the boulders consist of gray, medium-grained granitic rocks. Also present are boulders of acidic porphyries, basalt, diabase, anorthosite, sandstone, alaskite, quartz diorites (some from the Vermont pluton), metadiabase, metabasalt, mica schist, augen gneiss, banded gneiss, quartzite, hornfels, marble and aplite. The distribution of the different rock types in the conglomerates of the Griffith beds is not uniform. Metamorphic rocks are most abundant in the third and fourth members; acidic porphyries predominate in the conglomerate beds in the lowest member; boulders of metamorphosed basic igneous rocks and the associated Vermont quartz diorite are common in the lowest member. The other rock types are fairly evenly distributed.

Only the boulders from the Vermont pluton and its associated metamorphic rocks could be identified with the basement rocks in this area. Many of the other boulders are similar to rocks exposed in the Verdugo Hills and in the San Gabriel Mountains on the north side of San Fernando Valley. Anorthosite crops out over a large area in the San Gabriel Mountains (Miller, 1934). An unusual schist containing large porphyroblasts of feldspar is identical, in hand specimen, with a rock exposed in the San Gabriel Mountains, near Olive View San

ium. The assumption that much of the material in the Griffith beds is derived from the San Gabriel Mountains is based on the similarity of these rocks. The texture of the third and fourth members is like that of the present alluvial fans on the south flank of the San Gabriel Mountains. For this reason, it is suggested that the greater part of the Griffith beds is a fanglomerate.

Because of the occurrence of the Griffith beds in an isolated fault block, it is impossible to find direct evidence of its stratigraphic position in the Griffith Park area. Therefore the term "Griffith beds" is used for convenience without raising this unit to formation status. The rock types present in the conglomerates are different from the rocks in other conglomerates in this area; no similar formation crops out elsewhere in the Santa Monica Mountains. The southern part of the Griffith beds is tightly folded; the fold axes trend east-west. The axes are at an angle to all other axes of deformation in the Griffith Park area, and, unlike these other axes, these folds are unrelated to the fault block structure of this area. The deformation is more intense than in the other sedimentary formations in this area. The trend of the fold axes and the intensity of deformation in the Griffith beds are a basis for suggesting that this is the best unmetamorphosed sedimentary rock in the Griffith Park area.

Cahuenga Beds

The Cahuenga beds consist of five units or members; these are 1) a basal sedimentary breccia; 2) a coarse boulder conglomerate; 3) a lens of conglomeratic sandstone; 4) a sandy pebble conglomerate; and 5) a well-bedded conglomeratic sandstone. Except for the boulder conglomerate, these rocks are confined to the Cahuenga Peak block. A small amount of the boulder conglomerate is exposed in the southwestern part of the Griffith block and in the Ferndell block. The Topanga formation rests unconformably on the conglomerate in the Cahuenga Peak block and in the Ferndell block. A thick section of Cahuenga beds is missing at the base of the Topanga formation. The Cahuenga beds are folded by a broad anticline in the Cahuenga Peak block.

Sedimentary Breccia. The sedimentary breccia crops out on barren slopes or on slopes with a thin cover of soil that supports a sparse chaparral cover. The rock is massive; it consists of poorly rounded and angular fragments. The largest number of fragments consist of quartzite microbreccia and of blue andesite porphyry derived from the underlying microbreccia and andesite. A few well rounded pebbles of fine-grained quartz diorite and quartzite are present in the breccia. The fragments average 4 to 6 inches in diameter; few fragments larger than 6 inches were found. The breccia grades rapidly into the overlying conglomerate; the change in facies is marked by the appearance of boulders of medium-grained quartz diorite and granodiorite, coarse-grained pink granite, vesicular basalt, sandstone, and acidic porphyries.

Boulder Conglomerate. The conglomerate is a light tan-brown, deeply weathered, massive rock. The grain size is fairly uniform in general; locally small beds of pebble conglomerate and of sandy conglomerate are present. The lower few feet and the upper few feet of the

conglomerate are composed of cobble conglomerate, but the main part of the rock is a coarse boulder conglomerate, with boulders up to 4 feet in diameter. The matrix comprises about 30 percent of the rock and consists of coarse angular and subangular feldspathic sandstone. The most abundant rock type among the boulders is granodiorite. Other granitic types, such as pink coarse-grained granitic granite, gray medium-grained granite, quartz diorite, and alaskite are common. Pebbles of various acidic porphyries are also common. Vesicular basalt, basalt porphyry, aplite, sandstone, coarse-grained brown arkose, quartzite, mica schist, gneiss, and hornfels are very uncommon; pebbles of quartzite are common, but they are abundant only in small lenses of pebble conglomerate. The largest boulders are coarse-grained pink granite and vesicular basalt.

Sandstone Lens. Two areas of sandstone crop out within the conglomerate in the Cahuenga Peak block. The rock is a well indurated, cross-bedded and thick-bedded conglomeratic feldspathic sandstone, containing a few beds of sandy shale. The exposure near Hollywood Lake contains fewer pebbles and more shale than the sandstone in Brush Canyon. The rocks weather to a light tan, friable mass. The boulders and the composition of the sandstone are the same as in the conglomerate; the contacts with the conglomerate are sharp. The two areas of sandstone probably are parts of one lens.

Sandy Conglomerate. The sandy pebble conglomerate is a rock gradational between the boulder conglomerate and the overlying conglomeratic sandstone. The feldspathic sandstone matrix comprises 50 percent to 60 percent of the rock. The cobbles are better rounded and smoother than those in the boulder conglomerate. Because of better induration, this rock crops out in bold cliffs. The proportion of the rock types differs considerably from that in the boulder conglomerate. Pyritiferous diabase and medium-grained, gray granite are the largest and most abundant rock types; some boulders of diabase are 2 feet in diameter. The pebble-sized fragments consist of pink granite, quartzite, diabase, basalt, granodiorite, vesicular trachyte, andesite, aplite, and gneiss; quartzite is the most abundant of these rocks. Some of the diabase boulders are altered to yellow and blue clays that contain veins of halotrichite, jarosite, gypsum, and melanterite (Neuerburg, 1951a).

Conglomeratic Sandstone. The conglomeratic sandstone is a well-bedded feldspathic sandstone, containing thin discontinuous beds of sandy shale, and abundant boulders, mostly of pink granite. The boulders average 18 inches in diameter; some boulders are 3 to 4 feet in diameter. The pink granite boulders are present in all rocks of the Cahuenga beds and, except for the breccia, comprise a surprisingly uniform 2 percent. Small grains of smoky quartz occur in all rocks of the conglomeratic sandstone member, and serve to distinguish this sandstone from all others in the Griffith Park area. The sandstone consists of beds averaging 8 to 10 inches in thickness; each bed is graded. A small number of coarse boulder conglomerate lenses are present in the sandstone. These lenses consist of about 95 percent pink granite boulders that average 18 inches in diameter, and a few small pebbles of other granitic rocks, quartzite, and dia-

base. In several places, these large boulders rest on undisturbed thin beds of siltstone. Local unconformities and scour and fill on a relatively large scale are common in this member. In places, small irregular stringers of siltstone project upward into overlying sandstone beds, in the form of breaking waves. Small, undistorted shale and siltstone chips are common in the central parts of the sandstone beds; these chips are usually parallel to the bedding. A three-fold repetition commonly occurs in the sandstone beds; fine-grained sandstone, medium-grained sandstone, and coarse-grained sandstone. Coarse-grained sandstone is the most abundant type of sandstone.

The sandstone beds consist of 60 percent quartz, 10 percent potash feldspar, 5 percent plagioclase, 2 percent biotite, and a few fragments of muscovite and chert. Carbonate cement comprises about a quarter of the unweathered rock. The matrix in the conglomerate lenses is a coarse-grained, angular arkose, containing about three-fourths feldspar, mostly potash feldspar.

The structure and texture of this rock is not readily explained by normal current deposition. Large boulders of granite rest on undisturbed beds of shale and laminated siltstone; shale chips in sandstone beds are not distorted. Such features as these do not indicate deposition from moving currents, but suggest that the material was gently laid down on the underlying, probably soft material. Beds in the material that fill scoured channels show no relation to the sides of the channels; the stratification parallels perfectly the stratification in the surrounding rocks. This structure and texture is repeated without variation throughout the entire exposure of this conglomeratic sandstone that is about 1,000 feet thick. The texture is more characteristic of graywacke than of feldspathic sandstone. Such a texture is consistent with Kuenen's and Migliorini's theory (1950) of deposition of graywacke type rocks from turbidity currents (p. 110):

"With heavy sedimentation of largely arenaceous material in littoral waters, the seaward slope of the newly deposited detritus will increase progressively until the maximum angle of repose is reached. At this point, submarine slumping could be initiated by relatively insignificant agents, such as deep-reaching wave action during heavy storms or an especially abundant supply of sediment during floods. . . .

The seaward slope on which the slumps arose would be made up largely of loose arenaceous material (the argillaceous products of erosion would be carried farther out to sea), which, on slumping, would promptly be churned up into a turbid mass of higher density than that of the surrounding clear water. This mass would then flow down the submarine slopes until it reached the bottom, where it would spread out and deposit its suspended load as a graded sediment. In the intervals between the arrivals of the dense turbid clouds, normal sedimentation would continue and would be of a nature determined by the distance from the shore of the areas at which the clouds spread out."

Some such agent of transportation as turbidity currents from which large boulders could slowly settle down to rest on the underlying already deposited sediments without distorting these underlying sediments is necessary to explain the texture of this conglomeratic sandstone. The thin siltstone and shale beds may be normally deposited sediments, and the chips of shale and siltstone in the graded sandstone beds may be parts of these beds that were carried and redeposited by the turbidity currents. The presence of these chips in the central parts of the sandstone beds instead of at the base of the beds is best explained by deposition from turbidity currents, for they would not settle out until the turbulence of the suspen-

sion had abated or until its density had diminished. The sandstone beds are graded in the sense that the sizes of their largest grains decrease from the base upward, but at all heights, smaller grains of the entire range contained in the whole bed are found mixed with the larger ones, even the finest appearing from the base. Sedimentation by bottom currents could not bring about this form of grading because the size of the grains laid down at any instant would be limited to a very narrow range grouped about the maximum size transportable by the current velocity prevailing at the time of deposition. Sedimentation from a slowly moving turbid cloud would produce the type of grading described.

Age. The lithologic basis for assigning the beds to the Cretaceous has been discussed in a previous section. Deformed fish scales are common in the shaly partings in the conglomeratic sandstone. W. T. Rothwell, Jr., Richfield Oil Corporation, kindly identified the fish scales that were collected (U. C. L. A. loc. 2500). He compares them to a herring scale (*Xyng sp.* 293) from the lower "Topanga" formation in the San Joaquin Hills, Orange County, and from the lower Relizian shale in Cuyam Valley, Santa Barbara County. The geologic range of this fish is not known, and it may be considerable (D. Axelrod, p. c.). For this reason, as well as lithologic and structural reasons, no weight is placed on this fish scale for age determination.

Hoots (1931, p. 97-98) regarded the conglomerate in the Cahuenga beds as middle Topanga, basing his opinion on the presence of basalt boulders in the conglomerate.

The boulders of basalt that Hoots mentions are structurally and texturally unlike any basalt that is present in the Topanga formation in the eastern Santa Monica Mountains. Furthermore, the lithology of all of the rock of the Cahuenga beds is unique among the unmetamorphosed sediments of the eastern Santa Monica Mountains. The presence of beds of the lower member of the "basalt series" on conglomerate of the lower part of the conformable Cahuenga formation series is eloquent evidence that this unit is not above the "basalt series."

Tertiary Rocks

Topanga Formation

The Topanga formation has an aggregate thickness of 4,900 feet. It is composed of a lower member that consists of arkose and intrusive and extrusive basalt, a middle member that consists of basaltic graywacke, and an upper member that consists principally of conglomeratic arkose. The lower and upper members are exposed in the Ferndell, the Mount Hollywood, the Cahuenga Peak, and the Cahuenga Pass blocks; the middle member is present only in the Mount Hollywood and Ferndell blocks. The three members are separated from one another by unconformities, each representative of a considerable hiatus.

Lower Member. The rocks comprising the lower member of the Topanga formation are coarse and medium-grained arkoses, arkosic talus breccia, pebble conglomerate, shell limestone, alkali trachyte tuff, and extrusive and intrusive basalt. The tuff and basalt are described in a previous section. The chaotic inclusion structure of much of this member in the Ferndell and Mount Hollywood blocks does not permit accurate determination of the stratigraphic column within this member.

A suggestion of a basal conglomerate for this member occurs in three places. Highly polished quartzite pebbles in a thin bed that rests on the Feliz pluton at the base of the small outlier at the head of Brush Canyon. A small outcrop of the same quartzite pebble conglomerate is present in intrusive basalt just south of the quarry on the east side of Brush Canyon. Pebbles of the same highly polished quartzite are present in the fault gouge and along the trace of the Ferndell fault on the east side of Fern Dell. The pebbles may indicate a former shingle beach conglomerate derived from the Cahuenga conglomerate in the Ferndell block.

An indurated talus breccia is exposed along the west side of the Ferndell fault where the alluvium extends furthest north in Fern Dell; this is the same locality where the quartzite pebbles occur. The rock consists of large angular blocks of Feliz granodiorite, averaging 10 feet in diameter—some blocks are more than 30 feet in diameter—in a matrix of coarse angular arkose (cross-section DD', pl. 1). The talus is overlain by a thin irregular mass of coarse, angular, ill-sorted white arkose difficult to distinguish from the Feliz granodiorite. The talus breccia and the white arkose are not present elsewhere in the area. The presence of this talus breccia along the west side of the Ferndell fault and the lack of the Cahuenga conglomerate east of the Ferndell fault suggests that a fault scarp along the Ferndell fault was present during the deposition of the lower part of this member of the Topanga formation.

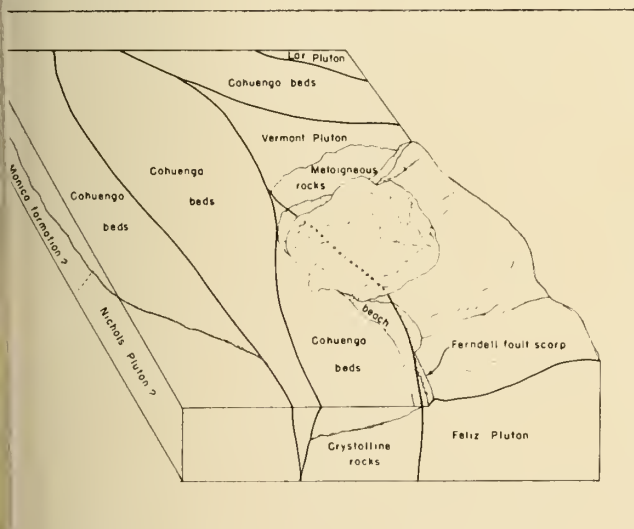


Figure 11. Generalized topography and geology of the Griffith Park area at the time of beginning deposition of the lower member of the Topanga formation in middle Miocene.

Arkose is the principal sediment of the lower member. It is a massive to poorly bedded, coarse to fine-grained, light-colored sandstone. Small pebbles of granitic rocks, quartzite, and basic and acidic porphyries are common; in a few places, pebbles are numerous enough to comprise a pebble conglomerate sandstone. Casts and shells of fossils are common, but not abundant. The weathered rock is brown, and contains no cement. The fresh rock is bluish gray and is cemented by calcite. In every place that it is exposed, a 1- to 2-foot layer of fault gouge is present



Figure 12. Fragments of a shell limestone bed in intrusive basalt. Griffith Park Road. Photo by John De Grosse, 1950.

along the contact between the arkose or the basalt and the underlying basement rocks.

A discontinuous 4-foot bed of shell limestone is present in the central part of the lower member. On the east side of the Ferndell fault, the shell limestone rests unconformably on intrusive and extrusive basalt and on arkose. In the western part of the Ferndell block it occurs as inclusions in intrusive basalt. The rock is very resistant to weathering and forms bold though small outcrops above the surrounding basalt. It is composed of oriented and distorted shells of oysters; a few distorted foraminifera are present. The rock analyzes 97 percent calcium carbonate; foreign material consists of fragments of crystals of hornblende, orthoclase, quartz, biotite, augite, analcite, zircon, and apatite. Numerous veinlets of calcite traverse the rock; the shell fragments are only slightly recrystallized. Contacts with intrusive basalt and inclusions of shell limestone consist of a pasty mixture of limestone and basalt.

Where the lower member of the Topanga formation is relatively undisturbed, the shell limestone appears to comprise a stratigraphic zone. Also, the brick red basalt flow breccia appears to comprise another stratigraphic zone about 50 feet above the shell limestone. The deposits of arkose and the accumulations of basalt below the stratigraphic horizons defined by the limestone and the flow breccia thicken very rapidly to the west and southwest into the Ferndell block and to the north of the main ridge in this area. The lowest arkose bed increases in thickness from a knife-edge to 100 feet under Mount Hollywood to about 1,000 feet at the southern end of the Ferndell block. This suggests that the Ferndell block was a rapidly sinking trough during the formation of the lower member of the Topanga formation. Further reason for believing that the Ferndell block was a mobile trough during the deposition of these rocks is the concentration of intrusive basalt in the northern part of this block; intrusive basalt is not common either in the southern part of the block or in the Cahuenga Peak and in the Cahuenga Pass blocks. The area of most intrusive basalt is close to the exposure of the

quartz diorite microbreccia, which therefore may have channeled the intrusion in the Ferndell block.

The occurrence of discontinuous beds of arkose and shell limestone that are interbedded with extrusive basalt and that are not inclusions in intrusive basalt suggests that deposition of these rocks was in isolated, small basins or that numerous minor unconformities are present in this member; probably both hypotheses are true.

West of Cahuenga Pass, the lower member of the Topanga formation of the Griffith Park area is underlain by lenticular conglomerates, sandstones, and shales that have a basal white arkose, which is present throughout much of the eastern Santa Monica Mountains (Terpening, 1951; Truex, 1950).

Middle Member. The middle member is composed of interbedded mudstone, conglomerate, conglomeratic sandstone, sandstone, and sandy shale. The composition is unusual; it is a dark chocolate brown, weathered rock, containing mostly basaltic detritus. I call this rock basaltic graywacke. Graywacke is probably a misnomer from the standpoint of composition (Pettijohn, 1949, p. 245), but it is an apt name insofar as texture is concerned.



Figure 13. Basaltic graywacke of the middle member of the Topanga formation, Griffith Park Road. Photo by John De Grosse, 1950.

The formation is ill-sorted for the most part, and it exhibits rapid textural variations from shale to a boulder conglomerate that contains boulders up to 3 feet in diameter in places. In a few places, the rock is fairly well bedded, but in general it is poorly bedded to massive. In one exposure a thin flow having pillow structure is present; this is the only crystalline basalt in this member. Small angular to subrounded fragments of various types of basalt are set in a matrix of dark brown, opaque, claylike material that has a waxy luster (chlorophaeite?). Mineral fragments consist of andesine, oligoclase, quartz, and augite, with minor amounts of myrmekite, analcite, biotite, and zircon. The boulders and cobbles consist primarily of augite basalt and olivine basalt,

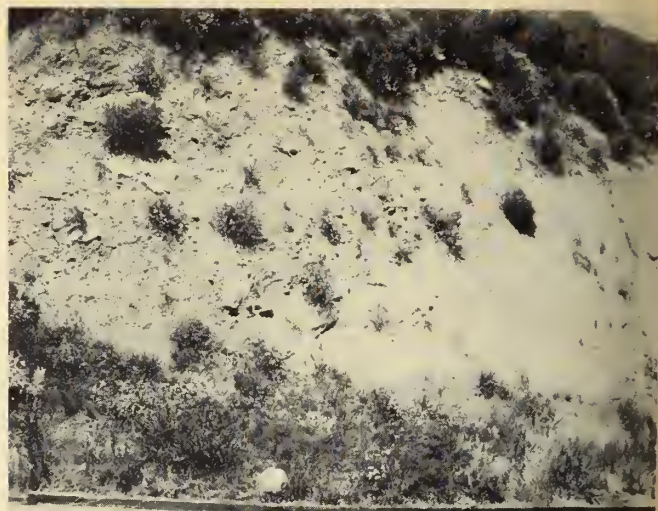


Figure 14. A filled river channel in granodiorite at an elevation of 1,000 feet, Griffith Park Road. Photo by John De Grosse, 1950.

with a few boulders and pebbles of pink granite, quartz diorite, quartzite, acidic porphyries, and arkose. The arkose is like that in the lower member of the Topanga formation. Large boulders and smaller fragments of the brick red basalt from the lower member are common in the lower parts of the basaltic graywacke.

The unconformity at the base of this member represents considerable erosion: three separated areas of this rock are present in Griffith Park. The area at the southern end of the Ferndell block and the area at the northern end of the block rest unconformably on the lowest bed of arkose in the lower member of the Topanga formation. The area underlying the main ridge east of the Brus Canyon fault rests unconformably on a bed of brick red basalt that is several hundred feet above the base of the lower member at this point. The basaltic graywacke is confined to the Mount Hollywood and Ferndell blocks. The three exposures, from south to north are respectively 700 feet thick, 300 feet thick, and 1,400 feet thick.

Upper Member. The upper member of the Topanga formation consists mostly of ill-sorted, coarse-grained conglomeratic arkose. Locally small lenses of medium-grained arkose and of coarse-grained arkose are present. A few beds of thin-bedded siltstone, sandy shale, and alkali trachyte tuff are present in the conglomeratic arkose. The rocks are well indurated and crop out above the underlying basaltic rocks of the lower and middle members. The weathered rock is light tan to brown; fresh specimens are bluish gray. Sorting is poor and the grains are subangular to subrounded. The mineral fragments are quartz, oligoclase, albite, orthoclase, biotite, sphene, zircon, apatite, and epidote. The pebbles are well rounded and smooth fragments of acidic and basic porphyries, quartzite, granite, quartz diorite, basaltic graywacke, scoriaceous brick red flow basalt, and alkali trachyte (?). Acidic porphyries and quartzite are the commonest and most abundant pebbles in the exposures of this member in the Mount Hollywood block. Basaltic rocks predominate among the pebbles in the conglomeratic arkose in the Cahuenga Pass block. Except for a sill that is intrusive in one place along the base of this member, basalt is not present in this member.

The upper member has a maximum thickness of 1,000 feet in the Mount Hollywood and Ferndell blocks and of 1,500 feet in the Cahuenga Pass block. The unconformity at the base of this member represents considerable erosion, and it rests on the lower member in Cahuenga Pass and on both the lower and middle members in the Mount Hollywood and Ferndell blocks. A small exposure of conglomeratic arkose, surrounded by alluvium, is present in the northern end of the Griffith block, where it presumably underlies the Hollycrest formation.

Ige. The only invertebrate fossils that were found in Griffith Park area are from the Topanga formation. These fossils are poorly preserved casts and shells in tuff, trachyte tuff, and in shell limestone. The localities in which fossils were collected are shown on the geologic map (pl. 1).

Table 3. Fauna of the Topanga formation (middle Miocene).*

	<i>Lower member</i>			<i>Upper member</i>
<i>arona</i>	2302	2306	2304	2303
vertebrata				
tropoda				
ulla sp. -----				c
ncellaria sp. -----				x
nus sp. -----		.		x
aritella ocoyana Conrad -----				x
cy-poda				
miantis sp. -----	x			
ardium (Trachycardium) quadrage-				
narium Conrad -----	c			x
ementia sp. ? -----	x			x
ementia (Egesta) pertenuis conra-				
diana (Anderson) -----				x
varicella cf. dentata var. eburnea				
Reeve -----			x	
sinita cf. ponderosa Gray -----	x			
da ochsneri Anderson and Martin --				c
icinisca cf. nuttalli Conrad -----				x
icoma sp. -----	c			
trea sp. -----	c			x
eten sp. -----		x		
eten cf. andersoni Arnold -----				c
eten cf. sancta-ludovicii Anderson				
and Martin -----				x
ropecten cf. mignelensis Arnold ----	x			c
ropecten crassicaudo Conrad -----	c			c
acoides sp. -----		c	c	c
acoides (Miltha) sanctaerucis Ar-				
nold -----		c	c	c
lina sp. -----			x	

x present; c = common.

The fossils are deposited in the collection of the Department of Paleontology, University of California, Los Angeles. The locality numbers are those of the University of California, Los Angeles.

P. Popenoe offers the following comments on the age of this fossil assemblage:

Of the forms specifically identified in the above list (table 3) the *Clementia* and the *Phacoides* occur in both Lower and Middle Miocene faunas in California, but apparently range farther than Middle Miocene; on the other hand, *Cardium drigenarium* and *Lyropecten crassicardo* are found in both Middle and Upper Miocene strata, but apparently do not occur in the Lower Miocene; the common occurrence of these species, in the added occurrence of *Turritella ocyana* thus fixes the age of the assemblage very clearly in the Middle Miocene, so-called 'Tombor Horizon' of the California Tertiary. The general aspect of the compared species in the check list is in full accord with this age assignment.

The presence of *Divaricella* is of interest in suggesting relationships of the fauna with that of the Caribbean. The genus is

known in California only in the Coyote Mountain 'Latrania' formation (Hanna, G. D., 1926, p. 454-455, 464-465, pls. 20, 26) and in the Altamira shale member of the Monterey shale in the Palos Verdes Hills (Woodring, W. P., Bramlette, M. N., and Kew, W. S. W., 1946, p. 28). The Altamira shale is probably slightly younger than the beds carrying *Divaricella* in the Santa Monica Mountains; the age of the Latrania sand is determined by some authors as Miocene; by others, as Pliocene."

Hollycrest Formation

The Hollycrest formation consists of thin-bedded, light brown, medium- and fine-grained arkose and white to gray silty clay shales. The arkose-shale ratio is about 5 : 1. The arkose is well-sorted and has graded bedding. The rock weathers to a soft clayey mass of sand containing numerous shale chips.

A thick pebble-boulder conglomerate comprises the basal member of this formation in the Griffith block. About 40 percent of the rock is a medium- to coarse-grained subangular arkose that weathers to a light tan friable mass. The pebbles and boulders are predominantly grandiorite, quartz diorite, pink granite, and diorite. A very small proportion of the boulders are brick-red basalt (from the lower member of the Topanga formation), alkali trachyte, andesite, dacite, and quartzite. A few, thin, persistent lenses of coarse-grained arkose and sandy clay shale are present in the conglomerate; these lenses are most abundant near the base of the shale. The contact between the sandstone and the conglomerate is conformable and gradational; thin beds of conglomerate are present in the lower 50 feet of the sandstone.

The formation is exposed in the Griffith, in the Cahuenga Peak, and in the Cahuenga Pass blocks. A small sliver of the conglomerate, resting unconformably on the upper member of the Topanga formation is present on the south side of the Griffith fault in the Mount Hollywood block. A small area of the conglomerate rests unconformably on granodiorite and is overlain by the Modelo formation in the northeast corner of the Mount Hollywood block. The conglomeratic member of the Hollyerest formation is confined to the Griffith block and to its near vicinity. The base of the sandstone, in the Cahuenga Pass block, is almost conformable with the underlying Topanga formation, but the shale continues east across the Cahuenga fault zone into the Cahuenga Peak block, where it rests unconformably upon the lower member of the Topanga formation and upon the conglomerate of the Cahuenga formation.

Age. The only exposure of a contact between the Hollycrest formation and the overlying Modelo formation in this area is in the northeastern corner of the Mount Hollywood block, where the Modelo formation rests on the Hollycrest conglomerate. The nature of this contact is not certain; it may or may not be a fault, as shown in plate 1. For this reason, the possible significance of this contact must be ignored.

West of Cahuenga Pass, the Hollycrest formation is conformably overlain by the Modelo formation and unconformably overlies the Topanga formation, locally with an angular discordance of 90°. Near Coldwater Canyon, the lower part of the Modelo formation is middle Miocene (R. Orwig, cited by Terpening, 1951, p. 22). This then fixes the age of the Hollycrest formation as middle Miocene.

The Hollycrest formation is lithologically distinct from both the Topanga and Modelo formations. Hoots (1931), Truex (1950), and Terpening (1951) have included it as

a member of the Topanga formation, principally because of the lack of the characteristic siliceous shales of the Modelo formation. However, the formation is conformable with the Modelo and not with the Topanga formation. The name Hollyerest is taken from the highest point in Cahuenga Pass, where the formation is well exposed.

Modelo Formation

The Modelo formation in the Griffith Park area is confined to a crumpled monocline on the east end of the Mount Hollywood block, where it rests unconformably on the Feliz pluton and on a thin sliver of the Hollyerest conglomerate. The lithology is distinct from that of other shales in this area. The formation is predominantly dark gray laminated calcareous organic siltstone and shale, with which a few beds of fine- to medium-grained orange and brown arkose and thin beds and discontinuous lenses of fine-grained orange limestone are interbedded. The rocks weather to a light tan color. Fragments of fish scales, wood, and leaves are abundant in these rocks; the wood fragments are most abundant in the siltstone and shale beds and appear to be absent in the limestone. A zone of gouge, 1 foot to 2 feet thick, is present between and parallel to the contact between the Modelo formation and the Feliz granodiorite in every place that it is exposed.

The lithology is not typical of the rest of the Modelo formation in the Santa Monica Mountains nor of that in the foothills east of the Los Angeles River; no siliceous sediments are present. Hoots (1931) collected foraminifera of upper Miocene age in this formation along the west bank of the Los Angeles River a few hundred feet south of Los Feliz Blvd. (Hoots' loc. 9); he mapped this occurrence as "lower Modelo."

Quaternary Alluvium

Two formations of alluvium are present in stream canyons and in the alluvial fans that are on the north, south, and east sides of the Griffith Park area. The older alluvium is exposed on the sides of canyons in their lower reaches and in the upper parts of the alluvial fans; an abandoned stream channel filled with poorly indurated conglomeratic alluvium is exposed at an elevation of 1,000 feet in granodiorite on the south flank of Mount Hollywood. The older alluvium is eroded. The younger alluvium fills canyon bottoms and is a thin veneer on the surface of the alluvial fans.

The older alluvium is poorly indurated; the younger alluvium is not indurated. Both formations consist of angular to subangular fragments, up to 10 feet in diameter, in an unsorted matrix of sand grains, silt, and clay. No bedding is evident. The fragments in the alluvium are derived from the underlying and surrounding rocks. The texture differs according to the rock types surrounding the alluvium; in the granitic rocks the alluvium is an unsorted coarse-grained, argillaceous arkose. In areas of sediments, the alluvium consists of a secondary conglomerate derived from older conglomerates or of a mixture of fragments of all rock types found in the surrounding sediments.

The two alluvial formations are probably both Quaternary, in view of their lack of induration—a fair criterion in southern California.

STRUCTURE

The structure of the Griffith Park area is dominated by high angle faults; folding, igneous activity, and sedimentation are clearly related to and controlled by the faults. These faults appear to have been active throughout the formation of all of the rocks in the area. The Cahuenga Peak, the Griffith, and the Ferndell blocks are the principal local basins in which the greatest thicknesses of sediments accumulated. The stratigraphy and structure of the area provide evidence of nine periods of major orogenic activity, and of several periods of minor orogeny.

The Griffith Park area is a discordant structural and stratigraphic element in the eastern Santa Monica Mountains. The structure of the eastern Santa Monica Mountains is succinctly described by Hoots (1931, p. 127):

"... forces of uplift recurrently active in the eastern part of the Santa Monica Mountains from the Jurassic period to the present have resulted in a pronounced, somewhat asymmetrical anticline. During the first periods of deformation ... uplift was concentrated in the central granite-slate area and produced a fold that plunged rapidly to the west and also to the east. The middle Miocene uplift of the central area appears to have produced several and possibly many major high-angle tension faults along the borders of the active area. ... Some of these faults were accompanied by intrusions of basalt ... In consequence of these recurrent periods of deformation the Santa Monica anticline is no longer a simple fold. Much of it has been disrupted by faults and basalt intrusions, and the southeastern limb of the fold is lost from view ... covered with alluvium."

The basement rocks of the Griffith Park area are different from and apparently unrelated to the basement rock west of Cahuenga Pass; the presence of rocks of the Nichols pluton in Forest Lawn (Neuerburg, 1951c) suggests that the antidiagonal structure of the eastern Santa Monica Mountains may continue east of the Los Angeles River, but offset to the north. The major lines of discontinuity that separate the discordant Griffith Park area from the normal Santa Monica Mountains structure are the Cahuenga fault zone and the Los Angeles River fault.

Faults

Most of the faults are not geometrical planes, but warped surfaces. These warped surfaces probably are primary, because most of the rocks, where they intersect the faults, do not show any deformation that might be attributed to folding of the fault surfaces. This is surprising inasmuch as no fault, with one exception, has a zone of gouge and breccia more than 1 foot thick. The fault probably originated as warped surfaces as a result of refraction in passing from one rock type to another and from one structure to another. Such behavior of faults was well established by Knopf (1929, p. 24) in the Moth Lode system of California, where it is possible to measure the index of refraction between slate and greenstone. Major changes in attitude—e. g., the Brush Canyon fault—probably resulted in passing from such incompetent rock, as brecciated or soft rock, to hard massive competent rock like the granitic rocks.

The major faults in the Griffith Park area that were most important in the structural and stratigraphic evolution of the area are the Cahuenga fault zone, the Brush Canyon fault, the Ferndell fault, the Griffith fault, the Hollister fault, and the Los Angeles River fault. The Cahuenga fault and the Brush Canyon faults define the Cahuenga Peak block, and the Hollister and the Griffith faults define the Griffith block. These two blocks contain

greatest thickness of sediments in this area; microbreccia may underlie the sediments for the full extent of each of these blocks.

Cahuenga Peak Block. The Cahuenga fault zone trends northwest by north along its northern exposed half, where it forms the contact between the Hollyerest formation and the Cahuenga beds. This part of the fault is on the south side of Dark Canyon where it approximates the line of sudden change in slope from the Cahuenga Peak hogback to Cahuenga Pass. The southern half of the fault is a series of subparallel, en echelon faults that separate the Cahuenga formation from the Hollyerest formation, and the Hollyerest formation, where it overlaps the Cahuenga formation, from the Topanga formation. The fault zone indicates that the Cahuenga fault curves to strike approximately north along its southern half.

The Brush Canyon fault follows the winding Brush Canyon on the south slope of the main ridge, where it generally strikes north. A few hundred feet south of the ridge, the fault begins to curve toward the west, and on the north side of the main ridge, it strikes approximately 60° W. The strike of the shear planes in the microbreccia of quartz diorite on the west side of Brush Canyon shows no systematic orientation; no relation to the Brush Canyon fault is apparent.

Both of these faults are offset by numerous faults having a few hundred to a thousand feet horizontal movement. The displacement along the Cahuenga and Brush Canyon faults is indeterminate. Both faults probably have about the same absolute displacement; the Cahuenga Peak block is a sedimentary unit that probably was thrust up as a single block. In no place is the displacement less than 100 feet. Extrapolation of the structure of the Cahuenga fault in the north part of the block to the surface of the basement rock would indicate a displacement on the order of 10,000 to 8,000 feet.

These faults were probably initiated with the brecciation of the quartz diorite. Later movement occurred between the deposition of the Cahuenga beds and Topanga formation, between the deposition of the Topanga and Hollyerest formations, and after deposition of the Hollyerest formation. The last movement probably was not great.

The direction of movement of the Cahuenga fault and the Brush Canyon fault, except for the last movement along the Cahuenga fault, is not apparent. It is difficult to conceive of the curved trace of the Brush Canyon fault as having originated other than by vertical movement. The Cahuenga Peak block was a graben during the deposition of the Topanga formation; it has been a horst since the beginning of the deposition of the Hollyerest formation.

Griffith Block. The Griffith block strikes about N. 60° W. and is situated in the northeast corner of the area. The northern suballuvial extension of this block is probably truncated by the Los Angeles River fault; the western extension either truncates or is truncated by the Cahuenga fault. The block is bounded by the Griffith fault on the south side and by the Hollister fault on the north side; between the two faults, the block, the fold axes in the Hollyerest formation in the block, and the foliation and the shear planes in the Lar pluton are subparallel and have approximately the strike N. 60° W.; the average dip is between 10° and 80° NE, although the faults are more nearly ver-

tical. The average strike and dip of the Nichols pluton (Neuerburg, 1951e) and the older rocks on the north flank of the Santa Monica antiform and the foliation and inclusions in the granitic rocks northeast of Griffith Park in the San Rafael Hills are about the same as in the Griffith block. This strike and dip would appear to be the regional attitude of the basement rocks in these contiguous areas.

A number of minor faults offset the Griffith and Hollister faults by a few hundred feet. The trend of the two faults is not a straight line; only a small part of the irregularities can be attributed to topography. The general direction of dip is to the north, but locally the Hollister fault dips to the south. The Griffith block is a graben except near the eastern end, where a rhomboid horst of the Griffith formation is present. Like the Cahuenga Peak block, the displacement on the boundary faults and the direction of movement are indeterminate. Were the Hollyerest formation the only sedimentary rock in the block, the displacement would be on the order of 1,500 feet, but if it is assumed that a complete section of the Topanga formation and Cahuenga beds and the minimum vertical component of the thickness of the Griffith beds underlie the Hollyerest formation, the minimum vertical displacement would be on the order of magnitude of 10,000 feet.

The Griffith block appears to have formed as a result of the shearing stresses that caused the foliation in the Lar pluton and that produced the zone of breccia and mylonite in the southern part of the Riverside block. Although, subsequently, the Griffith block was an important local trough of deposition, it does not appear to have been a topographic low during the deposition of the Griffith beds. The fold axes in the Griffith beds are the only axes of deformation in this area that are wholly unrelated to the fault block structure; the Griffith fault truncates these fold axes. Apparently the Griffith block remained inactive until after the deposition, folding, and perhaps erosion of the Griffith beds, when the block was downdropped to form a structural graben and a topographic trough. The block appears to have been a sinking trough throughout the deposition of the Topanga and Hollyerest formations. This condition probably accounts for the local accumulation of a basal conglomerate member in the Hollyerest formation.

Ferndell Fault. The Ferndell fault and the southern part of the Brush Canyon fault appear to define a block on the southwest corner of the Mount Hollywood block that was an important, rapidly sinking trough during deposition of the lower and middle members of the Topanga formation. The thickness of the lower member of the Topanga formation rapidly increases away from the core of granodiorite on the east side of the Ferndell fault into the Ferndell block. Further evidence for the existence of this block as a structural unit is the presence of an overturned syncline in the Topanga formation that is apparently confined to this block. Stratigraphic reasons for suggesting that a fault line scarp was present along the trace of the Ferndell fault at the beginning of deposition of the Topanga formation were given in a previous section.

The Ferndell fault is a hinge fault according to its present outcrop. The southern end of the fault has a minimum displacement of 1500 feet. The fault cannot be traced north of the Tunnel fault; the shell limestone beds are not

offset across any inferred continuation of this fault to the north. Two explanations are possible: 1) the fault is a hinge fault with no displacement at the north end where the distortion of faulting would be absorbed by the incompetent extrusive basalt accumulations in this area; or 2) the Ferndell fault is an old fault along which no recurrent movement has occurred and that is accidentally exposed by erosion. The only evidence favoring the first alternative is the truncation of the axis of the overturned syncline in the Ferndell block. This evidence is not conclusive for two reasons that suggest that this syncline is a frame fold confined to the Ferndell block. The axis of the syncline parallels the axis of the sedimentary-igneous wedge in the Ferndell block. The fold is not reflected in the older sediments on the west side of Brush Canyon, a condition which should prevail were the folding not confined to the Ferndell block.

The second alternative finds confirmation of a sort in three features. A hypothetical, concealed extension of the Ferndell fault on a line curving around to intersect the Brush Canyon fault just north of the point where it is offset by the Mount Hollywood fault (pl. 1), coincides with the approximate northern limit of the chaotic inclusion structure of the northern half of the Ferndell block. This line is also the axis along which the thickness of the lower member of the Topanga formation abruptly increases, and it probably represents the northernmost limit of the Cahuenga formation in the Ferndell block. Northeast of this line, the fold axes in the lower member of the Topanga formation trend northeast by east; south of this line, the fold axes strike about N. 45° W. Furthermore, the differences in stratigraphy along the exposed length of the Ferndell fault are much too large to be explicable on the basis of the apparent amount of movement shown by the Ferndell fault. These observed and inferred phenomena provide a sound basis for the hypothesized concealed extension of the Ferndell fault to intersect with the Brush Canyon fault, and for considering the Ferndell fault to be a branch of the Brush Canyon fault. Were the second alternative true, the displacement along the southern part of the Ferndell fault that involves Topanga rocks has taken place as a result of the folding of the rocks in the Ferndell block, but not as a result of active faulting.

Los Angeles River Fault. The existence of the Los Angeles River fault is based largely on the distribution of basement rocks (Neuerburg, 1951b and 1951c). The remarkably uniform trend of the structural planes and intrusive contacts in the Nichols pluton on the north flank of the Santa Monica anticline is assumed to hold true for the southeastward extension of this pluton under the alluvium. If this assumption is true, the presence of the Nichols pluton in Forest Lawn and the presence of spotted slate of the Santa Monica formation in the Seaboard well near the intersection of Figueroa Ave. and San Fernando Blvd. are conclusive evidence of the existence of the Los Angeles River fault. The truncation of the structure of the Griffith Park area along the Los Angeles River and the abrupt ending of the Santa Monica Mountains along this same line, and the failure of appearance of the structures and rocks of the Griffith Park area east of the Los Angeles River are further evidence for the existence of the fault.

The position of the fault that is shown on the accompanying plate is arbitrary; the true position is inde-

terminate. The strike of the fault that was chosen is also arbitrary, but it cannot be much different than the actual strike. It is based on the trend of the topographic line of truncation of the Santa Monica Mountains, on the position of the rock types, and on the fact that the igneous and metamorphic rocks in the San Rafael Hills are closely similar to the Nichols pluton. Movement on the fault is predominantly horizontal; it is a left lateral fault with a displacement of the order of magnitude of 6 miles.

Other Faults. Only a few of the numerous less important faults in the Griffith Park area merit brief mention. The Tunnel fault was so named by Klecker (ca. 1935), because the tunnel north of the Griffith Observatory was driven entirely in the fault gouge of this fault. This is the only fault in the area with a thick zone of gouge; the zone is about 40 feet thick at this point; elsewhere it is less than 2 feet thick. The Mount Hollywood fault has no vertical component of direction of movement. The direction of displacement of contacts by this fault requires that the movement was horizontal; the fault is a left lateral fault. Multiple structure and slickensides provide supporting evidence for this kind of movement.



Figure 15. Fault scarp and tunnel in fault gouge along the Tunnel fault. Vermont Ave. Photo by John De Grosse, 1950.

Folds

Three principal axes of folding are present in this area. The oldest of these axes are represented by the tight folds in the Griffith beds. These folds are the only folds that do not appear to be related to the fault-block structure of this area. Furthermore, the east-west strike of the fold axes is unique among the major folds in the eastern Santa Monica Mountains. The folding in the Griffith beds is confined to the relatively incompetent lower bedded part. Folding is not detectable in the massive upper conglomerate. The thick, massive conglomerate forms the northern limb of the northernmost anticline.

The next youngest axis of folding is the northeastward-trending anticlinal axis in the Cahuenga beds in the Cahuenga Peak block; this axis is also present in the Mount Hollywood block, north of the Ferndell block. This anticline was formed prior to the deposition of the Topanga formation for the lower member of this formation unconformably overlies the Cahuenga conglomerate.

th flanks of the anticline, where the Topanga formation comprises a less tightly folded anticline. Rejuvenation of this anticline after deposition of the Topanga formation produced an anticline in the Mount Hollywood block in the Topanga formation. As a result of this rejuvenation, the Topanga formation slid down the flanks of the anticline, the core of basement rock to produce a gouge zone along the contact that is mapped as a low angle normal fault (pl. 1).

The third group of fold axes trends northwestward. These are closely related to the trends of the major fault blocks that were troughs of deposition. The synclinal folding in the Cahuenga Pass block may be partly a result of movement along the Cahuenga fault zone. The overturned anticline in the Griffith block probably resulted in large part from the down-faulting of this block. The overturned anticline in the Ferndell block reflects the axis of major thickening in the Topanga formation, which roughly parallels the Griffith block. The overturned synclines dip away from the center of the area; for this reason, a north-south-trending anticlinal axis, not reflected in the remaining sediments, may be inferred in the central part of the area. The trend of this third group of fold axes parallels the major trend of folding in the eastern Santa Monica Mountains.

Uplift of the Griffith Park area after the deposition of the Modelo formation resulted in tilting the Modelo to the east along a north-south axis on the eastern end of the Mount Hollywood block. The Modelo formation slid along the contact with the Feliz pluton to form a low angle normal fault with a thin zone of gouge and to cause some unroofing of the strata along irregular axes that trend north-south. The axis of tilting is related to the structural pattern of the eastern Santa Monica Mountains; it may be related to the Los Angeles River fault, which it probably parallels.

Numerous minor folds are present in and related to the major folds in the area, such as drag folds in the overturned syncline in the Griffith block.

GEOMORPHOLOGY

The principal topographic feature in this area is the north-south-trending main ridge that is continuous with the main ridge of the Santa Monica Mountains and separated from it by the low gap that is Cahuenga Pass. This ridge does not appear to be controlled by geologic structure, for it is not parallel to the regional strike and is everywhere north of the tectonic axis of the eastern Santa Monica Mountains. The range is asymmetric, being steeper on the north; this is largely a result of the greater rainfall on the south side of the mountains.

Cahuenga Pass is underlain by soft shaly rocks and is between two areas of hard resistant rocks. Ridge-forming sandstones of the Topanga formation are on the south side of the pass. The hard sandstones of the Cahuenga formation crop out on the east side of the Cahuenga fault zone, which is on the east side of the pass. Thus Cahuenga Pass probably owes its existence to the presence of the soft rocks of the Hollycrest formation sandwiched between two areas of resistant rock. The Los Angeles River conceivably may have flowed through this pass prior to the last uplift of the Santa Monica Mountains.

The minor topographic features of the Griffith Park area are closely related to the geologic structure, more so than is true elsewhere in the eastern Santa Monica Moun-

tains. Many stream canyons follow fault contacts between rocks of unlike resistance to weathering; the best example is Brush Canyon which follows the southern part of the Brush Canyon fault. To an extent this close relation is surprising, inasmuch as gouge and breccia zones along faults in this area are very thin.

The south side of the main ridge, east of Mount Hollywood, is a compound fault-line scarp. The escarpment on the south side of Cahuenga Peak may be a fault-line scarp in part. The hogback containing Cahuenga Peak owes its existence to the underlying resistant Cahuenga conglomeratic sandstone and sandy conglomerate.

GEOLOGIC HISTORY

The following sequence of events seems a probable explanation of the evolution of this area.

1. Plutonic intrusion of gabbro into unknown rocks.
2. Hypabyssal intrusion of basalt and diabase into the gabbro.
3. Intrusion of the Vermont pluton, in two stages, into the older basic igneous rocks, and metamorphism of these older rocks.
4. Intrusion of the Lar pluton under shearing stress in the northern part of the area.
5. Shearing and brecciation of the basement rocks between the Lar pluton and the Vermont pluton as a result of the same forces that caused the foliation of the Lar pluton, and brecciation of the Lar pluton in the Cahuenga Peak block. This period of orogenic activity probably resulted in the formation of the Cahuenga, the Brush Canyon, the Griffith, and the Hollister faults, and in the formation of the troughs that controlled deposition of the sediments.
6. Intrusion of the Feliz pluton; the region of intrusion was controlled in part by the zones of breccia in the older rocks.
7. Brecciation of the part of the Felix pluton that was intruded along the site of the Griffith block.
8. Shearing of the quartz diorite microbreccia in the Cahuenga Peak block.
9. Intrusion of malchite in the Lar pluton in the Riverside block. Intrusion of andesite porphyry dikes into the quartz diorite microbreccia in the Cahuenga Peak block, under near surface conditions.
10. Erosion and partial subsidence of the area.
11. Deposition of the Griffith beds on the planed surface of basement rocks; the lower part was deposited in the sea; the upper part grades up into a fanglomerate derived from the Verdugo Hills, which were emergent at this stage.
12. Folding of the Griffith beds, and downfaulting of part of the folded rocks into the Griffith block.
13. Erosion to an area of gentle relief, followed by gradual subsidence.
14. Deposition of the Cahuenga beds.
15. Folding of the Cahuenga beds into a gentle anticline, and then down faulting into the Cahuenga Peak, the Ferndell, and the Griffith blocks.
16. Erosion of the area, with the formation of a highland area of basement rocks in the Mount Hollywood block, east of the Ferndell fault-line scarp.
17. Subsidence of the area with the Ferndell and Griffith blocks forming rapidly subsiding troughs.
18. Deposition of the lower member of the Topanga formation; volcanic activity concentrated in the Ferndell block and along the southern side of the Griffith block; volcanoes of basalt in the Riverside block and in the eastern end of the Mount Hollywood block.
19. Uplift and deformation along the northeast-trending anticlinal axis.
20. Erosion, followed by subsidence and deposition of the middle member of the Topanga formation. Very little volcanic activity. The areas that were eroded were underlain principally by basalt.
21. Uplift and deformation along the northeast-trending anticlinal axis.
22. Erosion, followed by subsidence and deposition of the upper member of the Topanga formation; explosive eruption of alkali trachyte ash.
23. Uplift and deformation along the northeast-trending anticlinal axis.

24. Erosion, followed by subsidence and deposition of the Hollywood formation. Local deposition of a basal conglomerate in the Griffith block, which was a rapidly subsiding trough.
25. Uplift and deformation of the area to produce northwest-trending synclines.
26. Erosion, followed by complete subsidence and deposition of the Modelo formation.
27. Uplift and deformation. (Direction of deformation being controlled by movement along the Los Angeles River fault?)
28. Erosion and deposition of alluvium in stream canyons and in alluvial fans.
29. Uplift, followed by erosion of the older alluvium and deposition of the alluvium now accumulating in the bottoms of canyons and on alluvial fans.

ECONOMIC GEOLOGY

Quarries

Three quarries are present on the east slope of Brush Canyon in Miocene basalt. Quarrying was begun by the Los Angeles Stone Company (Merrill, 1916, p. 486). The product was crushed stone, used mainly for concrete aggregate. The capacity of the plant was 1,000 tons per day. A large tonnage was removed; stockpiles, now overgrown with brush, are present in several places near the quarries. Some of this stone was used in home construction in the surrounding area. In 1921, the quarry was purchased by the Union Rock Company (Tucker, 1921, p. 322); this company increased the capacity to 2,000 tons per day in 1926 (Tucker, 1927, p. 342). The quarries were abandoned in 1929 (?), and are now used occasionally for a movie location.

A small quarry is on the west side of Brush Canyon in the quartz diorite microbreccia; it is abandoned. On the eastern slope of the canyon west of Brush Canyon, the remains of a screening plant, obviously used in connection with this quarry, is present. Some of the material from this quarry was used by local residents for retaining walls. Information on this quarry was not available. The Los Angeles Park Department is quarrying and crushing the Lar quartz diorite on the north side of the Riverside block and west of Hollister Drive for use in surfacing park roads and playgrounds.

Mines

A 100-foot adit is present in the Cahuenga breccia in a small canyon on the west side of Brush Canyon. Local tradition has this mine being an old Spanish gold mine. A short adit is present in basalt on the east side of Brush Canyon east of the above-mentioned mine. The adit is rumored to be an abandoned copper prospect, but no copper minerals were to be found.

The Mexicans dug a lime kiln in the side of a hill on the north side of the Riverside block, just east of Hollister Drive. Calcite was obtained from thick veins along faults in the Lar biotite quartz diorite nearby and in the Hollywood conglomerate in the small hill, about a mile west of the kiln. Blocks of shell limestone were also brought from the south side of Mount Hollywood for calcining.

Hollywood Lake

The reservoir called Hollywood Lake is a part of the Owens River aqueduct system, and was built as an impounding reservoir to serve Hollywood and the surrounding area. The dam is named Mulholland Dam and was built in 1924-25 by the Los Angeles Department of Water and Power. The dam is located in Weid Canyon east of

Cahuenga Pass; it is 210 feet from foundation to crest, 933 feet long and 16 feet wide at the crest.

Following the failure of the St. Francis Dam in 1928 public opinion forced numerous investigations of the Mulholland Dam to be made to determine the safety of the structure (Anonymous, 1934, p. 558). Despite repeated assurances from the investigating boards that the structure was safe, it was finally necessary to construct an earthfill on the downstream face of the dam. This construction was admittedly for the psychological effect:

"Filling the canyon below the dam and planting shrubs and trees would change the apparent menace to a pleasing view carrying no suggestion of a dam." A small dam was subsequently built in the northern part of Hollywood Lake to provide additional reservoir capacity.

Engineering Geology

At one time, the City Council of Los Angeles considered the possibility of providing further access to San Fernando Valley by tunnels through the Griffith Park area. (Jessup, 1933); seven alternate routes were suggested. At present the City of Los Angeles is preparing to drive an aqueduct tunnel from Brush Canyon to Hollywood Lake.

REFERENCES

- Anonymous (1934) Mulholland Dam backed by earth fill against downstream face: *Engineering News Record*, vol. 112, p. 558-560.
- Campbell, I., and Schenck, E. T. (1950) Camptonite dikes near Boulder Dam, Arizona: *Am. Miner.*, vol. 35, pp. 671-692.
- Elam, J. G. (1948) Geology of the Seminole quadrangle, Los Angeles County, California: Unpub. M.A. thesis, University of California at Los Angeles.
- Hanna, G. D. (1926) Paleontology of Coyote Mountain, Imperial County, California: *Cal. Acad. Sci., Proc. ser. 4*, vol. 14, p. 247-503.
- Hazenbush, G. C. (1950) Geology of the eastern parts of the Diablos Canyon and Las Flores quadrangles, Los Angeles County, California: Unpub. M.A. thesis, University of California at Los Angeles.
- Hoots, H. W. (1931) Geology of the eastern part of the Santa Monica Mountains, Los Angeles County, California: *U. S. Geol. Surv. Prof. Paper* 165-C, pp. 83-134.
- Hoots, H. W. (1932) Generalized geology of the eastern part of the Santa Monica Mountains in *Guide Book 15*, 16th Internat. Geol. Congr., pp. 40-43.
- Jessup, J. J. (1933) Report on Griffith Park Tunnel plan, City of Los Angeles, February 1933, to the City Council of Los Angeles.
- Klecker, J. B. (ca1935) Geologic map of Griffith Park, Unpub. Senior Problem, University of California at Los Angeles.
- Knopf, A. (1929) The Mother Lode system of California: *U. S. Geol. Surv. Prof. Paper* 157.
- Kuenen, Ph. H., and Migliorini, C. I. (1950) Turbidity currents: a cause of graded bedding: *Jour. Geol.*, vol. 58, pp. 91-127.
- McGill, J. T. (1948) Geology of a portion of the Las Flores and Diablos Canyon quadrangles, Los Angeles County, California. Unpub. M.A. thesis, University of California at Los Angeles.
- Merrill, F. J. H. (1916) Mines and mineral resources of Los Angeles County, Orange County and Riverside County: *California Mineral Resources*, vol. 15, p. 486.
- Miller, W. J. (1934) Geology of the western San Gabriel Mountains of California: *Univ. California Publ. Math. and Phys. Sci.*, vol. 1, pp. 1-114.
- Neuerburg, G. J. (1951a) Minerals of the eastern Santa Monica Mountains, Los Angeles City: *Am. Mineralogist*, vol. 36, p. 15-159.
- Neuerburg, G. J. (1951b) Evidence of a major fault truncating the eastern end of the Santa Monica Mountains, California: (abstract) *Geol. Soc. America Bull.*, vol. 62, p. 1509.
- Neuerburg, G. J. (1951c) Petrology of the pre-Cretaceous rocks of the Santa Monica Mountains, California: Unpub. Ph. D. thesis, University of California at Los Angeles.
- Pettijohn, F. J. (1949) *Sedimentary rocks*, Harper and Brothers, New York.
- Stepper, A. W. (1931) Geology of the Glendale-Eagle Rock district: Unpub. Senior Problem, Univ. California, Los Angeles.

ening, J. N. (1951) Geology of part of the eastern Santa Monica mountains: Unpub. M.A. thesis, University of California at Los Angeles.

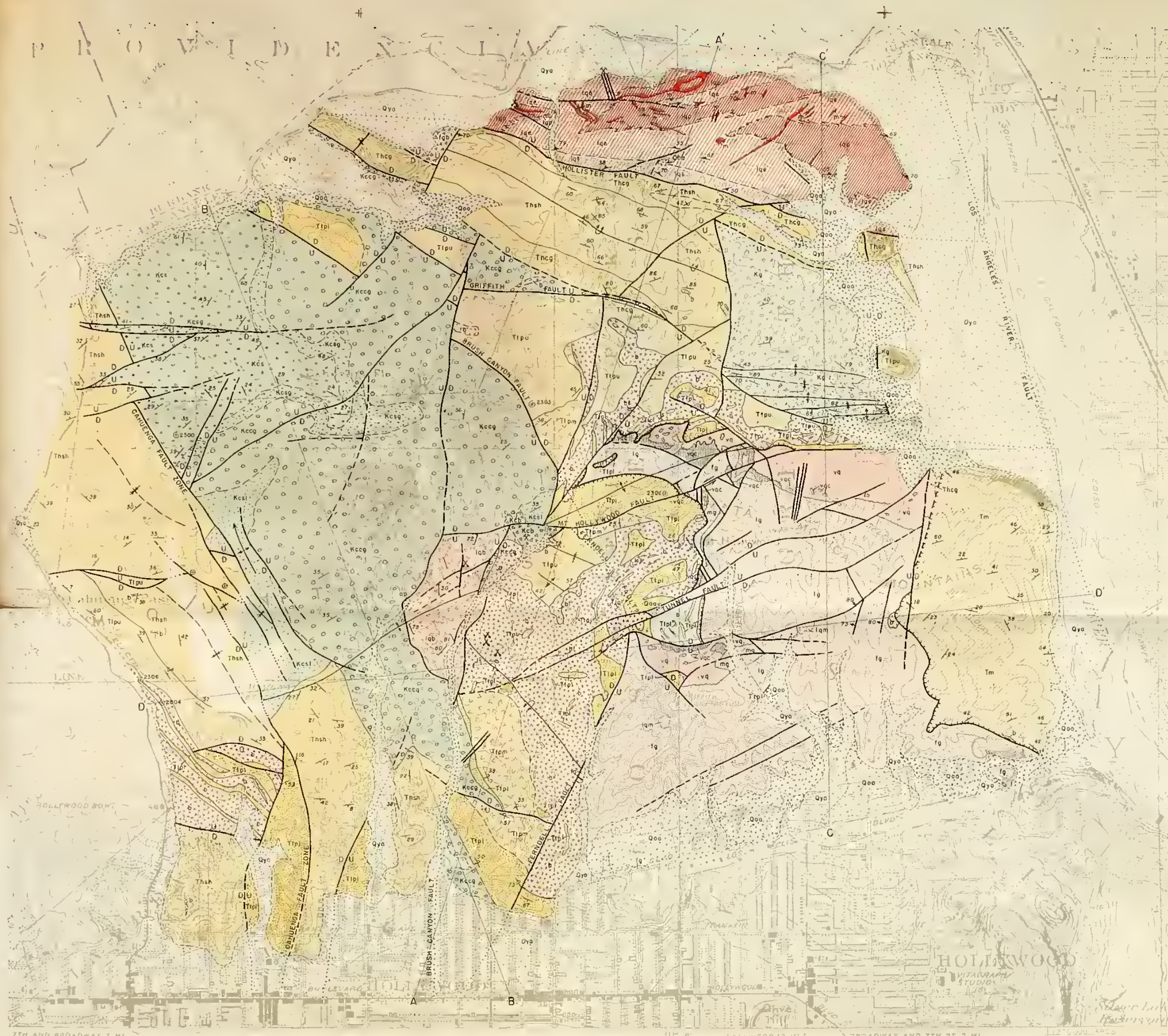
ex, J. N. (1950) Geology of the northern part of the Santa Monica Mountains between Beverly Glen and Laurel Canyon boulevard: Unpub. M.A. thesis, University of California at Los Angeles.

Tucker, W. B. (1921) Los Angeles field division, Los Angeles County: California Min. Bur. Rept. 18, p. 322.

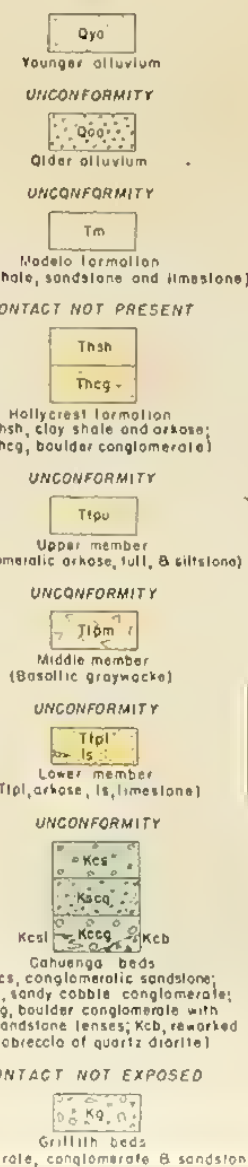
Tucker, W. B. (1927) Los Angeles field division, Los Angeles County: California Min. Bur. Rept. 22, p. 342.

Woodring, W. P., Bramlette, M. N., and Kew, W. S. W. (1946) Geology and paleontology of Palos Verdes Hills, California: U. S. Geol. Surv. Prof. Paper 207.

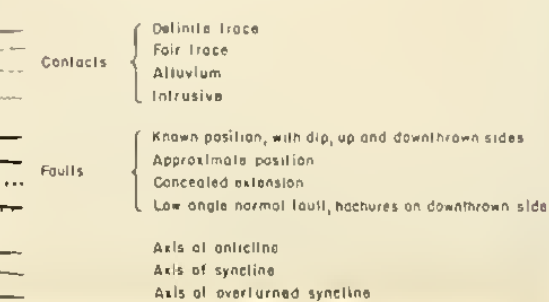
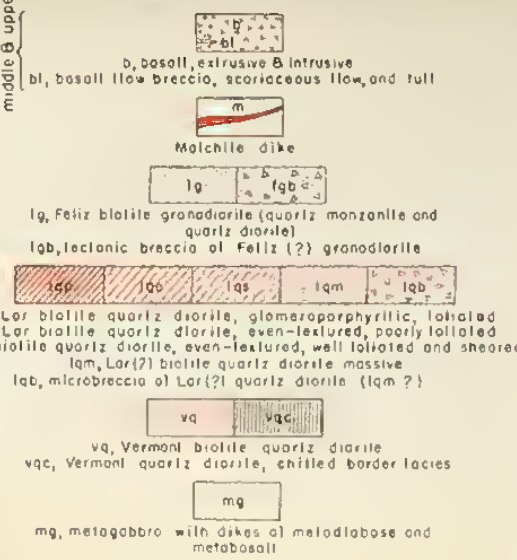
O



SEDIMENTARY ROCKS



IGNEOUS ROCKS



GEOLOGIC MAP AND STRUCTURE SECTIONS
OF THE
GRIFFITH PARK AREA
LOS ANGELES COUNTY, CALIFORNIA
Geology by George J. Neuerburg, 1945-1949

